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The Innovation Effect of the Energy Transition in Germany

An Exploratory Empirical Analysis of Firms and their Innovation Activities

Dissertation

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Johanna Katharina Auguste Pütz

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Content overview

Abstract

Germany is currently undergoing a profound transformation of its national energy system through an abatement of greenhouse gas emissions and a simultaneous phase-out of nuclear energy. This energy transition, *Energiewende*, was first conceived by ecological and anti-nuclear movements in the 1970s, introduced into politics in the 1990s and 2000s, and became societal consensus following the Fukushima nuclear incident of 2011. The achievement of its objectives relies on a shift from fossil and nuclear energy to renewable energy sources and an overall reduction in energy consumption. This is a significant challenge for Germany's energy-intensive economy and centralized, fossil fuel-based energy system. It entails more distributed electricity generation, higher volatility of supply, different requirements to the electricity grid and infrastructure, and structural changes to the energy system and its actors. A successful transition will require comprehensive socio-technical change such as the development, introduction and diffusion of new technologies, infrastructure, organizations, and business models. To address this challenge, the political strategies and policies that devise and implement Energiewende seek to induce private firms to deliver the necessary novelties. Innovation is considered key to achieve Energiewende objectives, reduce the costs of transforming the energy system, and bolster the international competitiveness of German firms in the environmental and green energy space. Especially firms of the energy technology value chain, i.e. firms providing products or services related to the production, transport and consumption of energy are encouraged to explore, develop, implement and adopt technological and organizational solutions for the energy transition.

To date there is a limited understanding to what extent and how Energiewende policies have indeed fostered such innovation and there are several controversies regarding their effect. Most importantly, controversies exist regarding the impact of the Energiewende's core policy Renewable Energy Sources Act (*Erneuerbare Energien Gesetz, EEG*), the effect of the proclaimed "accelerated Energiewende" after Fukushima in 2011, and the changes triggered inside of firms. These controversies are due to three research gaps: first, Energiewende is often reduced to a single policy and not understood as a complex, systemic transition process, second, research with a comprehensive understanding of innovation is missing, and third, there is a lack of investigations on the actor level.

This thesis contributes towards closing the research gaps and addressing these controversies by investigating the innovation effect of Energiewende through a series of

qualitative, exploratory company case studies. An integrated conceptual framework that draws on the multi-level perspective in sustainability transitions research, environmental economics, and organization and management studies is used to investigate corporate innovation activities with episodic interviews with managers of incumbent and start-up firms from the energy technology value chain. The objective of the thesis is to clarify the recurrent controversies in the empirical assessment of an innovation effect, identify areas of tension, and draw implications for policy makers and firms as to how to induce and navigate innovation in the context of socio-technical change. Due to the exploratory, case-study based nature of the empirical research findings are not universally representative and applicable.

The case study findings indicate that the Energiewende policy mix had a mostly positive effect on innovation activities. Especially the strengthening of particular markets and the systemic change induced by policies such as the Renewable Energy Sources Act (*Erneuerbare Energien Gesetz, EEG*) presented firms with disruptions and opportunities to which they responded with innovation activities. This holds for innovation activities in a wide range of products, services, business models and internal organizational structures. The EEG in particular seems to have triggered innovation activities not only in the immediate technology area of RES technologies, but furthermore also in complementary technologies and – through the systemic change it enabled – also in wider systemic solutions. The accelerated Energiewende following Fukushima led incumbent energy suppliers to intensify innovation in their business models and boosted Energiewende-related innovation activities that were already ongoing in energy technology and materials firms. Inside of firms, innovation activities were influenced by strategic, structural and organizational parameters. For incumbent firms especially, the response to the changing energy system was tainted by a corporate cognition revolving around the superiority of a fossil-nuclear based energy system. The analysis also finds tensions with regards to the effect of Energiewende policy on innovation, in particular with respect to path dependence of systemic regulation, an emphasis on short-term incentives, and the focus on the national political jurisdiction. Implications from these results for policy makers and firms are presented.

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Abbreviations

A.o.	Among others
BDEW	Bundesverband der Energie- und Wasserwirtschaft; German Association of Energy and Water Industries
BDI	Bund der Deutschen Industrie; Federation of German Industry
BEE	Bundesverband Erneuerbare Energie
BMU	Bundesministerium für Umwelt; German Federal Ministry for the Environment
BMWi	Bundesministerium für Wirtschaft und Energie; German Federal Ministry for the Economy and Energy
BNetzA	Bundesnetzagentur; German network industries regulator
CDU	Christlich Demokratische Union Deutschlands
CHP	Combined heat and power
CO_2	Carbon dioxide
Div.	Diversified
EEG	Erneuerbare Energien Gesetz; Renewable Energy Sources Act
EEWärmeG	Erneuerbare Energien Wärmegesetz; Renewable Energy Sources Heating Act
EFI	Expertenkommission Forschung & Entwicklung; Commission of Experts for Research and Innovation
EKFG	Energie- und Klimafonds; Energy and Climate Fund
EnEV	Energieeinsparverordnung; Energy Savings Decree
EnLAG	Energieleitungsausbausgesetz; Energy Grid Expansion Act
EnWG	Energiewirtschaftsgesetz; Energy Industry Act
EPIA	European Photovoltaic Industry Association
FDP	Freie Demokratische Partei
FIT	Feed-in tariff
Foc.	Focused
GDP	Gross domestic product
GHG	Greenhouse gas(es)
I.a.	Inter alia; among others
Ibid.	Ibidem; in the same place; the last source previously referenced
I.e.	Id est; that is
IEA	International Energy Agency

IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KBV	Knowledge-based view (of the firm)
KWKG	Kraft-Wärme-Kopplungsgesetz; Combined Heat and Power Act
MAP	Marktanreizprogramm, MAP; federal support scheme to increase the deployment of RES in buildings
MLP	Multi-level perspective
NAPE	Nationaler Aktionsplan Energieeffizienz; National Action Plan on Energy Efficiency
n. d.	No date
NO_x	Nitric oxide and/or nitrogen dioxide
OECD	Organization for Economic Cooperation and Development
PV	Photovoltaics
R&D	Research & development
RBV	Resource-based view (of the firm)
RES	Renewable energy sources
RES-E	Electricity from renewable energy sources
RES-H	Heating from renewable energy sources
RES-T	Transport from renewable energy sources
SEM	Single European Market
SNM	Strategic niche management
SO_2	Sulfur dioxide
SPD	Sozialdemokratische Partei Deutschlands; Social Democratic Party
StrEG	Stromeinspeisegesetz; Feed-In Law
Tech.	Technology
TM	Transition management
UK	United Kingdom
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
US/USA	United States/United States of America
ZEW	Zentrum für Europäische Wirtschaftsforschung; Centre for European Economic Research

1 Introduction

1.1 Background

Germany is currently undergoing a profound transformation of its national energy system as it shifts its electricity supply from conventional fossil and nuclear energy sources to renewable energy. This transformation is characterized by a dual objective where the abatement of greenhouse gas (GHG) emissions is pursued in parallel with the phase-out of nuclear energy. Since the installation of the electricity grid network in the late 19th century Germany relied on large power plants fired with hard coal, lignite and nuclear power, to cover its electricity demand. The oil crisis of the 1970s, the Chernobyl nuclear accident of 1986, and growing anti-nuclear, environmental, and climate protection movements, however, fostered mounting concerns regarding the environmental impacts, safety, and security of supply of such an energy system. First political initiatives to increase the use of renewable energy sources (RES) in the 1990s led to the adoption of the Renewable Energy Sources Act (*Erneuerbare Energien Gesetz, EEG*) and a feed-in tariff subsidy scheme for electricity from renewable sources in 2000 and subsequently an unprecedented growth in renewable electricity generation. The long-term strategy to drastically reduce greenhouse gas emissions by moving to a nearly full electricity supply from renewable sources and significantly cutting energy consumption were stipulated in the 2010 Energy Concept (*Energiekonzept)*. Controversial for decades, the nuclear question was resolved in 2011 when the nuclear accident at Japan's Fukushima Daiichi power plant led the government to accelerate the phase out of nuclear energy. The term *Energiewende* became mainstream use afterwards and replaced previous discourses on nuclear phase-out and renewable energy.

Energiewende is shaped by a political course of action. The overarching targets, set by the 2010 Energy Concept and its 2011 amendment following Fukushima, encompass a nuclear phase-out to zero capacity in use until 2022 as well as a 40% reduction of GHG emissions by 2020 and 80-95% by 2050, compared to 1990 levels. Achieving these overarching targets depends on changes to the supply of energy, especially through the increased use of renewable energy, and changes to the demand for energy through increased energy efficiency. The Energy Concept also sets targets pertaining to these areas:

- Renewable energy: gross final energy consumption 18% share by 2020, 60% share by 2050; gross electricity consumption 35% share by 2020, 80% share by 2050
- Energy efficiency: primary energy consumption reduction of 20% by 2020, 50% by 2050, compared to 2008 (Bundesregierung, 2010)

The Energiewende strategy is implemented through a mix of policy instruments which regulate, incentivize and support behavior that will help achieve the targets described. The policy mix covers several areas incl. renewable energy, energy efficiency, electricity market design, emissions trading and transmission and distribution grids. Key policies include the Renewable Energy Sources Act (*Erneuerbare Energien Gesetz, EEG*) of 2000 as well as its various amendments, public support for research and development in energy technologies such as the Energy Research Program (*Energieforschungsprogramm*) and standards and regulations for the energy consumption of products and processes.

An energy system without GHG emissions and nuclear energy will significantly differ from the one that Germany has hitherto relied on. Changes are still materializing as the transition has not yet reached a final state. However, several changes seem probable: On the supply side, capacity installed for power generation is becoming more distributed. Electricity from renewable sources (RES-E) is typically generated on a smaller scale, which means that there will have to be a larger number of production sites in order to be able to cover the electricity demand. Also, the majority of electricity production from renewable energy sources (RES) will likely take place far removed from centers of demand as the bulk of electricity from wind is generated in Germany's North, while population hubs are in the middle and the south of the country. In addition to that, electricity production is getting more volatile as RES are subject to natural fluctuations of e.g., solar irradiation or wind and cannot easily be dispatched at will. On the demand side, industrial and residential electricity consumers are backward integrating and turning into power producers as generation capacity is installed on and in private buildings. This means instead of simply taking energy from the grid they may also feed into the grid, become self-sufficient and go off-grid, or alternate between the two. These developments pose challenges for energy security and the balancing of supply and demand. On the physical side, the grid will need to be able to transport electricity larger distances and distribute electricity as well as collect it. On the virtual side, energy management, i.e. the ability to increase or reduce electricity generation or consumption, is becoming more important in all nodes of the system. An additional challenge is to manage stability in the system as a whole given the risk of volatility. Electricity markets need to be designed in a way that they provide the right price signal for individuals to take decisions that create a well-functioning system for everybody. With all of this may come the necessity for energy storage of various forms from large hydro pumped storage to batteries or power-to-gas storage systems. Lastly, as a consequence of these changes to the system, the actors in it and the balance of power among them will change as well. This has already started to materialize with the slow demise of the large electricity suppliers – previous monopolists and cash cows in the system.

To accomplish the energy transition, Energiewende politics must ensure a successful development of the energy system towards its future target state, although the exact state is not yet clear. Novelties will have to emerge and ultimately form a new system. This may require the development and implementation of new technologies, infrastructures, organizations, and business models. An important objective of Energiewende politics is hence to contribute towards the transition of the energy system by fostering "innovation". The Energiekonzept as well as related publications by the Federal Ministry for Economic Affairs and Energy mention the importance of innovation in many instances (BMWi, 2012a, 2014f; Bundesregierung, 2010). For the success of Energiewende, innovation is needed to:

- Lower the costs and increase the performance of technology
- Develop solutions for current barriers of Energiewende
- Secure technological leadership and competitiveness of German firms (Bundesregierung, 2010)

Energiewende and innovation are interrelated. While Energiewende is expected to influence corporate innovation, a relationship exists in the reverse as well. Corporate innovation will determine the success of Energiewende and the intensity or direction it takes may itself trigger political reactions. Furthermore, as Energiewende and corporate innovation take place and change over time, a complex web of interdependencies and linkages is likely to emerge.

While 2016 has marked the fifth anniversary of the current Energiewende strategy and many policies have their origins long before this, the innovation impact of Energiewende has hitherto not been fully investigated and sufficiently assessed. The official monitoring reports for Energiewende do not include systematic assessments of the innovation effect (Löschel, Erdmann, Staiß, & Ziesing, 2014c). Other academic publications vary widely in their conclusions and range from identifications of an overall positive effect on innovation dynamics (Ragwitz et al., 2014; Ragwitz, Huber, & Resch, 2007) to inconclusive results (Wangler, 2012), and indeed even negative effects (Böhringer, Cuntz, Harhoff, & Otoo, 2014; EFI, 2014; Frondel, Ritter, Schmidt, & Vance, 2010). Three controversies are particular striking. First, there is a controversy around the innovation impact of the Renewable Energy Sources Act (*EEG*), the legislative center piece of Energiewende. Second, there is disagreement to what extent and how the "accelerated Energiewende" after the Fukushima nuclear incident induced additional innovation activities. Third, arguments revolve around the extent to which Energiewende has triggered changes within incumbent firms in the electricity and energy technology sectors.

1.2 Research questions and objectives

The motivation of this doctoral thesis is to address this knowledge gap and help reconcile the conflicting empirical evidence. Given the lack of empirical knowledge regarding the firm level innovation effects of Energiewende, the research interest of this thesis is a comprehensive exploration of such an effect. The guiding research question is hence:

What is the impact of Energiewende on corporate innovation?

To investigate this question the two main concepts, Energiewende and corporate innovation, will need further clarification. Both will be defined in more detail later in this thesis (cf. sections 2.3 and 3.2). To briefly summarize the definitions here: Energiewende is understood as a political course of action that drives a transition towards sustainability, more specifically the transition of the German energy system towards being free of GHG emissions and nuclear energy. Corporate innovation is understood as the intentional and targeted invention, implementation and diffusion on parts of private firms of a subjectively new or improved product, process, strategy, organization or business model that is perceived to be relevant in the context of Energiewende. The focus of this thesis is hence explicitly on the activities of private firms. While all types of organizations and even individuals can engage in innovation activities, profit-oriented, private sector firms are at the centre of delivering the innovations sought after by the policy makers of Energiewende. They contribute the majority to economic activity in Germany and have the capabilities to not only invent and develop new solutions, but also implement and diffuse them. The research interest and in particular the broad definitions of Energiewende and innovation as well as the focus on private firms addresses research gaps currently found in the literature on an innovation effect of Energiewende, they will be presented in more detail later (cf. section 4.3).

Overall, the investigation of the research interest throughout this thesis proceeds in three steps, each of which is further subdivided into three research questions:

First, Energiewende is positioned in the context of innovation from both a theoretical and a substantive point of view. The following research questions are asked:

I.1. What is Energiewende and what are its claims regarding innovation?

I.2. What is the current evidence to suggest an effect of Energiewende on innovation? What research gaps and controversies exist?

I.3. How can Energiewende be positioned in the relevant academic literature?

Second, the effect of Energiewende on corporate innovation is empirically explored. With respect to this empirical investigation the following three research questions are asked:

II.1. How have German firms over time changed their innovation activities in the light of Energiewende?

II.2. What is the impact of the individual components of the Energiewende policy mix on these innovation dynamics?

II.3. What is the impact of confounding factors and how do they interact with the components of the Energiewende policy mix?

Third, the findings from the empirical investigation are used to draw implications that are relevant to politics and firms. This involves answers to the following research questions:

III.1. How have the case study findings addressed the controversies in the existing literature?

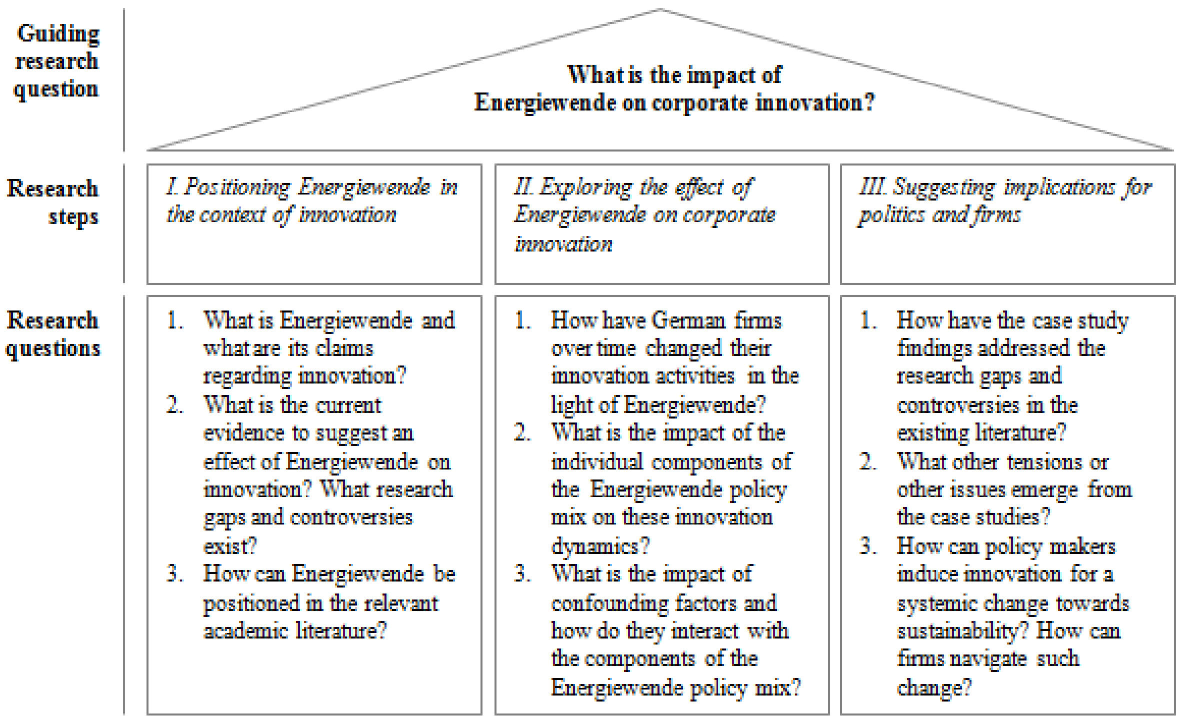
III.2. What tensions or other issues emerge from the case studies?

III.3. How can policy makers induce innovation for a systemic change towards sustainability? How can firms navigate such change?

Figure 1 provides an overview of these research steps and questions.

By investigating these research questions this thesis will shed light on the innovation effect of the German energy transition especially with respect to corporate reactions in terms of innovation activities. In addition to expanding the general understanding of the innovation effect of a socio-technical transition such as Energiewende and contributing to the respective academic literatures, the objective of this is to provide policy makers and firms with better strategies to navigate innovation in the context of socio-technical transitions towards sustainability. The contribution of this is threefold: First, for academia, research gaps and controversies in the ongoing debate on the innovation effect of the energy transition will be clarified. Second, policy makers in Germany will get insights into how Energiewende influences innovation and consequently get cues for how to induce corporate innovation activities in light of a systemic transformation towards sustainability. Third, firms will be able to compare their own innovation activities to findings of the empirical research and challenge their existing strategies for coping with external influences such as a politically-induced change.

Figure 1: Overview of research questions



1.3 Research design

This doctoral thesis is positioned in the academic field of the multi-level perspective in sustainability transition studies, a growing body of research that investigates socio-technical transitions towards a more sustainable society from an interdisciplinary point of view (Geels, 2002, 2010, 2011; Markard, Raven, & Truffer, 2012). The literature holds that transitions are complex, multi-faceted processes that evolve over time and can therefore not properly be captured in linear cause-effect relationships. While this perspective is very suitable to investigating a complex systemic transformation such as the transition of the energy system in Germany, a couple of adjustments need to be made to be able to adequately address the research questions. Sustainability transitions research does typically not assess the effect of policies and does not study actors. Therefore the empirical investigation in this thesis relies on an integrated conceptual framework that combines basic premises from sustainability transition studies with insights from environmental economics and organization and management studies. The conceptual framework structures the data collection and analysis process and provides cues for the interpretation of research findings. Given the exploratory research interest no hypotheses are formulated. As such the analysis remains flexible and open to new, unexpected insights emerging throughout the empirical investigation.

The empirical investigation relies on qualitative research methods and uses exploratory case studies of firms in the energy technology value chain. A total of 37 case studies were conducted. The case studies combine interviews with managers of these firms with primary and secondary data collected from websites and other public data sources. The interviews are the core of the data collection and provide an insider's perspective to the research question that cannot be obtained from archival data research. The interviews were conducted in a semi-structured way employing an episodic interview style that integrates narrative elements with conceptual answers to questions.

The choice of an exploratory research design with an integrated conceptual framework and qualitative methods is appropriate given the open nature of the research interest, the limited existing knowledge in this area and the complexity and interrelatedness of the phenomenon under study. Qualitative research aims to understand phenomena by taking into consideration their complexities and specific social contexts. This means the research is not designed to test the causal relationship between two variables, but rather to generate new knowledge and understand the nature of interaction of a set of factors whose boundaries are often unclear (Flick, 2014, p. 90; Lamnek, 2006, p. 216). Such a design is especially applicable to research topics that are complicated as they stretch across a large variety of actors and an extended period of time and have not been sufficiently explored before (Flick, 2014, p. 150). All of these apply to the research interest at hand. Given the exploration of a complex phenomenon through selected qualitative case studies, the findings of this thesis are not universally applicable or generalizable beyond the specific context set by the research interest. A more detailed explanation of the conceptual framework as well as the research design, methods and limitations will follow later in this thesis (cf. chapter 5 and section 6.1).

1.4 Structure of the thesis

This thesis is organized in eight chapters. Table 1 provides an overview of the structure with the main chapters and their contents, as well as the respective research questions they address (cf. Figure 1).

Chapter 1 (this chapter) provides an introduction to the entire thesis with a review of background, research objectives and questions, research design, and structure of the thesis.

Chapter 2 introduces the theoretical foundations of the thesis including the origins of innovation studies in the works of Joseph A. Schumpeter and other early contributors (section 2.1) and the three different strands of theoretical literatures relevant to studying the research questions of this thesis; sustainability transitions research (section 2.2.1), environmental economics (section 2.2.2), and organization and management studies (section 2.2.3). Furthermore the concept of innovation for this thesis is defined (section 2.3).

Chapter 3 turns to the substantive core of this thesis, the German Energiewende. It first elaborates that anthropogenic global warming and climate change have made transitions towards a more sustainable energy system a phenomenon in many countries around the world today (section 3.1). Next it defines the use of the term Energiewende in this thesis (section 3.2) and turns to a brief historical review of the German energy transition from its early days during the oil crises and green societal movements of the 1970s to the 2016 worries about target achievement (section 3.3). In the course of this review, strategy, policy instruments and policy process of the Energiewende policy mix are presented in their respective historical contexts. The last section of the chapter (section 3.4) deduces the implicit and explicit targets of the German Energiewende policy regarding innovation.

Chapter 4 summarizes the current state of research regarding an innovation effect of Energiewende in both the official monitoring process installed by the federal government (section 4.1) as well as the empirical investigations and reviews of independent academic researchers (section 4.2). The chapter concludes by pointing out three research gaps and three controversies found in the current state of research in order to address them by the empirical research carried out later in this thesis (section 4.3).

Chapter 5 develops the integrated conceptual framework for the empirical investigation drawing on the previously elaborated strands of literature (sections 5.1 and 5.2). It also presents the firms of the energy technology value chain as the research case of the empirical investigation and points out different groups of firms in the value chain and the specific role that innovation has in their sector (section 5.3).

Chapter 6 constitutes the core of the empirical investigation and therefore the longest chapter in the thesis. First, research methods and process employed in the qualitative case studies are described (section 6.1). Second, the findings of the case studies are presented in thick descriptions organized by research question and following the main elements of the conceptual framework: changes to innovation activities and the development of innovation dynamics (section 6.2), impact of the Energiewende policy mix (section 6.3) and impact of context factors and firm characteristics (section 6.4).

Chapter 7 takes the qualitative case studies one step further and presents an extended discussion of the findings. First, the three controversies identified earlier (cf. section 4.3) are revisited in lights of the findings of the empirical research in this thesis (section 7.1). Second, three areas of tension impeding innovation in the context of Energiewende and which emerged throughout the case studies are elaborated (section 7.2). Then, the results are reviewed in terms of implications for policy makers and firms (section 7.3).

Chapter 8 concludes the doctoral thesis with a summary of main results and contributions along the research questions (section 8.1), a discussion of limitations and avenues for further research (section 8.2) and a final overall conclusion (section 8.3).

Table 1: Main chapter structure of the thesis

Thesis Chapter	**Research question addressed**
1. Introduction Background, motivation, research questions and approach	
2. Theoretical foundations of innovation and transition studies Origins of innovation studies and three relevant literatures to the research question	
3. Energiewende and its intended innovation effect History of the energy transition and review of innovation as a policy objective	I.1
4. Current state of research regarding an innovation effect Review of current state of empirical research, identification of three controversies	I.2
5. Conceptual framework for empirical enquiry	I.3

Integrated research framework based on sustainability transitions, environmental economics and organization and management studies	
6. Findings of exploratory company case studies Corporate perceptions of Energiewende and changes in their innovation activities	II.1-3
7. Extended analysis and discussion Three controversies revisited, emerging tensions and implications for politics and firms	III.1-3
8. Conclusion Summary of findings, contribution, avenues for further research	

2 Theoretical foundations of innovation and transition studies

This chapter lays out the foundations of this dissertation in terms of the theoretical literature in innovation studies and clarifies the use of the terms Energiewende and innovation in this thesis going forward.

Innovation studies is a large and diverse research field that spans across several academic disciplines. Following the works of Joseph Schumpeter a large number of researchers in economics and business have studied innovation related to economic growth, the role of firms, and the role of politics. For the research interest of this thesis, three theoretical literatures are of particular importance: sustainability transitions research, environmental economics, and organization and management studies. Sustainability transitions research, especially the multi-level perspective, has become a useful umbrella for the investigations of transitions towards a more sustainable society taking an interdisciplinary and evolutionary perspective. Environmental economics is the main literature body where investigations of the innovation effect of environmental policy take place. Organization and management studies is concerned with the role of firms in innovation i.e. how they are affected by external change and how they respond to it in terms of innovation activities.

The chapter proceeds as follows: First, the origins of innovation studies in the works of Joseph A. Schumpeter as well as basic concepts related to the role of politics and firms in the process of innovation are introduced (section 2.1). Second, the multi-level perspective in sustainability transition studies (section 2.2.1), environmental economics (section 2.2.2) and organization and management studies (section 2.2.3) are elaborated in turn, focusing on assumptions and major contributions that may be relevant to the research questions. Due to the vast size of the innovation literature the review of its theoretical foundations in this chapter, however, remains at a rather high level[1]. Third, the definition of innovation for the use in this thesis is established (section 2.3).

[1] More detailed introductions to the field are provided by e.g., Cohen (1995, 2010) with respect to the economics and industrial organization literature post-Schumpeter, Ahuja, Lampert and Tandon (2008) regarding innovation in the management literature, and Jaffe, Newell and Stavins (2003) discussing the economics of technological change including different theoretical underpinning, and Markard, Raven and Truffer (2012) or Geels (2002, 2004) for sustainability transitions and the multi-level perspective.

2.1 Origins and basic concepts in innovation studies

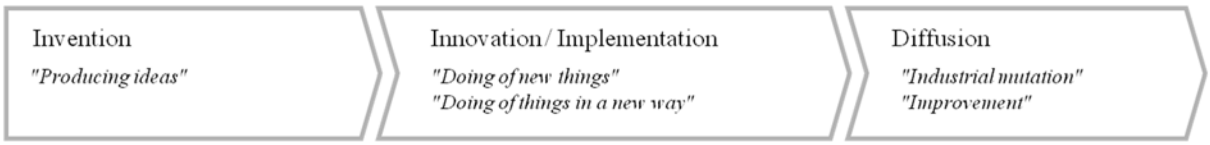
2.1.1 Schumpeter and creative destruction

The academic study of innovation has its roots in the theories of economic progress and technological change advanced by Joseph Alois Schumpeter in the first half of the 20th century. Schumpeter was the first to identify innovation in the form of *creative destruction* as key to economic change and develop hypotheses about the drivers of innovation activity. His theories on innovation constitute the foundation for the field of innovation studies across all subject disciplines.

Schumpeter studied the process of change in a capitalist society and observed that economic progress is achieved when conventional ways of doing things are replaced by new and better ways. In a continuous process of renewal *innovations* are introduced to society, gain popularity, overtake and eventually replace what was previously there. They become the new status quo until they in turn are pushed aside by the next cycle of innovations. Schumpeter called this renewal process *creative destruction* (1942), a term that encapsulates that a status quo is overhauled in a radical, possibly violent way, but that hints to the constructive beginning of something new and better.

Schumpeter's theory is usually summarized in a linear, process-based model in which economic change proceeds in three steps (Godin, 2006; Jaffe, Newell, & Stavins, 2003). The first step, *invention*, means coming up with a new idea, often achieving a scientific or technological breakthrough that leads to the development of a new product or process. This novelty, however, has no value by itself. It only develops significance for economic progress if it is put to proper use. Here comes *innovation*, i.e. the *implementation*, of the new idea. Innovation means for "getting things done" (Schumpeter, 1947, p. 152). It captures the realization of the new idea on part of the innovator, who can, but does not need to be the inventor. Typically this is associated with the commercialization or introduction to market of an invention, but non-market implementation may of course be equally important (Jaffe et al., 2003). Lastly, in order to have an effect on the wider economy, the innovation needs to spread. *Diffusion* is the third step and denotes the adoption of the innovation by other economic actors and hence its successful establishment in a market. Change on an economy-wide level is the cumulative economic effect of these three steps.

Figure 2: Simple 3-step innovation process model after Schumpeter (Quotes from Schumpeter, 1942, 1947)



In the Schumpeterian theory innovation is endogenous, i.e. it is understood as the subject and result of economic activity. Schumpeter attributed innovation to the activities of entrepreneurs and private companies that pursue the introduction of novelties in anticipation of financial rewards. He proposed two models of evolutionary process in capitalism: In his Mark I theory entrepreneurs found innovation-based companies, successfully grow them and replace established business in the process. For this they need the proper entrepreneurial spirit, an "aptitude that is present in only a small fraction of the population" (Schumpeter, 1942, p. 132). They cede entrepreneurship when their companies become the new generation of established ones constituting a new generation of business. Industry incumbents are hence defenders of the status quo that are overcome by the new and better ways of entrepreneurial companies. In his Mark II theory Schumpeter expands this view to include innovation "from within" (Schumpeter, 1942, p. 83) established firms. Focusing on organizational aspects rather than individual and industrial ones as in Mark I, Schumpeter asserts that successful firms do both at the same time; hold on to routines and engage in innovative activities. Large firms are able to re-invest excess profit from monopolistic activities into workforce and research and development thereby increase production and in turn generate more profit and continue to grow. Barriers to innovation may exist in both. An individual entrepreneur is often faced with a lack of financial resources to realize their idea or impeded by other external resistance to change, a large established organization finds it difficult to break with routine activities and avoid organizational complacency and gluttony (Andersen, 2013).

While especially after Schumpeter innovation became closely associated with technological change, Schumpeter does not limit innovation to technological aspects only. He mentions at least five ways "to reform or revolutionize the pattern of production", several of which may supersede a mere technological definition (Schumpeter, 1942, p. 132):

1. Introduction a newly invented or improved product
2. Introduction of a new production process
3. Development of a new source of supply
4. Development of a new market for products

5. Reorganization of an industry

To take away, Schumpeter created the field of innovation studies by developing a process-based concept of innovation where innovation is – on a micro level –the exploitation of a new idea, which leads to– on a macro level – the change of economic structures over time. While technological change is important, Schumpeter's view of innovation is not limited to technological aspects only, but includes all kinds of renewals. Change is a key characteristic of capitalism. The economy is changing all the time and equilibrium is only a transient phase.

While Schumpeter's conception of the innovation process still prevails today it has also been taken up and adjusted by various literature streams as explained in the upcoming sections.

2.1.2 Innovation and economic growth

The interest of economists in the study of innovation surged when technological change was found to be an important driver of economic development and prosperity. While the first formal model, today known as *neoclassical growth theory,* still considered technological change an *exogenous* and residual factor in economic growth, subsequent models of the *new growth theory* placed innovation at the core of economic development and studied it as an *endogenous* factor resulting from the growth of knowledge through private and public investments in technological research and development and human capital.

Robert M. Solow (1956, 1957) developed the so-called *neoclassical growth model in* which he formalized the link between economic development, increases in labor and capital, and technological change[1]. Using a Cobb-Douglas production function where the two production factors labor and capital determine output, Solow studied economic growth in the United States in the first half of the 20th century. He found that the productivity growth observed in that period could not be explained by the corresponding increase in the two conventional production factors alone. Since economies only accumulate wealth when they increase output in relation to the size of their labor force, it is relative measures such as output per capita that capture the value of economic growth to residents of a country[2]. Solow

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[1] Independent of Solow, Trevor W. Swan (1956) developed a similar model. Therefore the elaborated model is also referred to as the *Solow-Swan Neoclassical Growth Model*.

[2] This statement is over-simplified for the sake sticking to the line of argument; economic research has long demonstrated that in addition to relative economic output other factors such as health, education distributional issues may also play a role (cf. e.g., (Easterlin, 1995; Rodrik, Subramanian, & Trebbi, 2004; Stiglitz, 2012).

found that a remaining factor, the so-called *Solow residual*, explains much of the productivity increase. On average about 60 % of growth in labor productivity per country is attributed to this effect today (Easterly & Levine, 2002). Solow coined the residual "technical change", or, "any kind of shift in the production function" (Solow, 1957, p. 312) and framed it as an exogenous factor that occurs spontaneously in an economy. Without elaboration of origin or antecedents technology assumed to be a public good that is widely available in a perfect market. The impact of the neoclassical growth model on innovation research is hence ambiguous: while it asserted the importance of innovation, it did not address how innovation is achieved and limited its study from the outset by declaring it exogenous.

This view was challenged by the *new growth theory* and *endogenous* models of economic development (Lucas, 1988; Romer, 1986, 1987). Instead of taking innovation for granted and studying its impact on productivity and growth, scholars in this tradition sought to identify the components of the Solow residual by including them explicitly in their growth models. The objective was to find out what influences technological change, why the Solow residual varies across countries and to what extent economic growth continue. Studies with endogenous models showed that technological change is not "manna from heaven" (Freeman, 1994, p. 463), but the result of deliberate investment in factors that drive productivity. The most important factor was found to be the stock of knowledge embodied in humans and technology (Arrow, 1962b; Lucas, 1988; Romer, 1986). Humans develop their knowledge stock through education or experience. The technological knowledge stock grows through the exploration, development and implementation of technology through for example investments in research and development (R&D), a factor that has empirically been linked to economic growth (Griliches, 1979; Grossman & Helpman, 1990; Romer, 1986, 1990).

2.1.3 Market failures and innovation policy

Establishing that innovation is not exogenous, but the result of the activities of economic actors opened the door for economists to analyze the functioning of the market for innovation. Several market failures were identified, which in turn provided the rationale for innovation policy in order to pursue socially-optimal levels of innovation.

Independent of new growth theory, the *induced innovation hypothesis* provided evidence that innovation is a "purposive economic activity" (Jaffe et al., 2003, p. 469) and technological change therefore endogenous. Sir John Hicks noted in the 1930s that a change in the relative prices of production factors triggers invention targeted at optimizing the use of these production factors in the new price setting (Hicks, 1932). This induced innovation hypothesis was formalized in economic models by several researchers in the 1960s (Ahmad, 1966; Kamien & Schwartz, 1968) and developed further in the 1970s (Binswanger, 1974). While Hick's hypothesis targeted process innovations i.e. changes to the way that production factors are used in the production process, the same logic may apply to product or other types of innovations.

Research showed that neoclassical assumptions that the market for innovation was perfectly competitive[1] and would thus result in a socially-optimal level of innovation could not be upheld. The most important market failure in the context of innovation stems from the special nature of knowledge. Knowledge that is created in the innovation process is a nonrival or public good that appreciates with use. Once it has been created it can be shared and used by other economic actors and therefore multiplies in value. The creation of knowledge through private innovation activities hence has positive externalities that yield dynamic increasing returns to society (Romer, 1994; Stiglitz, 2008). However, it also means that since investor in knowledge creation are not rewarded for these positive externalities, they do not have the incentive to provide knowledge creation to the extent desirable from a social point of view. Hence private investments in human capital and R&D are likely to be below the socially-optimal level (Coe & Helpman, 1995; Lucas, 1988; Romer, 1986, 1987, 1990).

In addition to the positive externalities of knowledge, more failures in the market for innovation were discovered over time. Monopoly power plays a role since the products of knowledge creation such as new technologies are not always available to all economic actors, but subject to monopolistic practices (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Romer, 1990). Intellectual property rights targeted at inducing innovation through limiting the positive externalities explained above may indeed create such a market failure (Swann, 2009). In addition to this, monopolies can also occur naturally around innovations due to increasing returns to scale of information and network externalities. Lastly, information asymmetries between buyer and seller may exist and impede the innovation process (Swann, 2009).

The academic field of innovation economics and innovation policy is fundamentally concerned with devising policies in order to address market failures that cause an under-

[1] Neoclassical theories often implicitly work with the assumption of complete markets with perfect competition, equilibrium pricing at the intersection of supply and demand, and rational economic actors (Weintraub, 1993).

investment in innovation. Three types of policy instruments are typically distinguished in innovation policy, depending on where in the innovation process they intervene in order to address market failures: supply-side measures, or *technology-push,* and demand-side measures, or *demand-pull*, and framework conditions, or *systemic policies*. The distinction emerged in the 1960s and has been the topic of fierce debates, especially between technology-push and demand-pull policy instruments (Di Stefano, Gambardella, & Verona, 2012).

The technology-push perspective is rooted in the Schumpeterian and other (Bush, 1945; Godin, 2006; Rogers, 1962) linear models of the innovation process where technological change is the ultimate consequence of scientific research and invention. Therefore politics can best support innovation by strengthening invention and innovation through e.g., granting property rights or directly financing research and development activities (Mowery & Rosenberg, 1979; Myers & Marquis, 1969). In contrast to that demand-pull proponents argue that innovation is the result of market forces. Demand-side and market factors such as latent demand (Schmookler, 1962, 1966), the potential to develop new markets (Vernon, 1966), customer and user utility (Von Hippel, 1976, 1994), or changes to market factor prices (Hicks, 1932) are needed to trigger innovative activities by companies in the first place. They therefore call for policy makers to influence the market demand through financial support for the adoption of new technology or public procurement. In addition to the direct positive effect on technological diffusion, demand-pull policies are expected to have an indirect, dynamic effect on earlier stages of the innovation process (Schmookler, 1962; Von Hippel, 1976). It has, however, become consensus now that both, technology supply and market demand, are required for technological progress and that the sequence and interaction of them plays a critical role. Depending on the barriers and challenges to innovation existing in a particular situation both types of policies plus conducive framework conditions may be needed (Di Stefano et al., 2012; Nemet, 2009).

2.1.4 Firms as actors in innovation

Firms are important actors in the innovation process as their "activities aggregate into overall levels of economic performance" (Hall & Soskice, 2001, p. 6). They conduct innovation activities when their expected return outweighs the costs. Several factors influence this expectation of a return.

Firms are active throughout the innovation process and especially critical in the later stages that entail the implementation and diffusion of a novelty (cf.

Figure 2). For invention, companies invest in R&D, and set up and operate large laboratories and research centers that work on the generation of new ideas, scientific breakthroughs and technological inventions. However, invention also takes place outside of corporate realms and without an immediate commercial purpose, for example in military research centers and universities (Nelson, 1993) or through individual and collective initiatives (Quiggin, 2006; Von Hippel, 2001). Of the three innovation process steps, companies are even more important in the latter ones. The actual innovation, that is the implementation of the idea often through commercialization, bringing-to-market and scaling-up, takes place almost exclusively through business organizations. Even if some ideas at first flourish and spread outside and without the involvement of firms, a corporate organization is usually taken on at some point (Audia & Rider, 2005).

It has been well-established that companies invest in innovation activities because they expect an economic return from it (Arrow, 1962a; Cohen, 2010; Griliches, 1957; Nelson, 1971; Schmookler, 1962). While theories of the firm have evolved beyond the conception of companies existing for the sole purpose of maximizing profit, the basic tenet that firms are rational actors and are therefore profit and value oriented still holds (Jensen, 2001; Rumelt & Lamb, 1997). All the activities that companies can engage in with the purpose of creating and introducing novelties are hence investment activities that are ultimately geared at generating profit, increasing the value of the entity that undertakes the activity, and securing longer term corporate survival. The challenge of innovation activities is that these investments do in general not generate a timely and certain return. Investments in innovation are linked to great uncertainty over their outcome including the risk of complete losses and long pay-off times. Companies hence need to take these risks into account in their investment decisions. This is especially true for investments related to activities very early in the innovation process. Early inventive activity such as basic R&D, i.e. research that is not yet geared towards a specific commercial application, or creative activities and experimentation are far from delivering a return on investment (Von Hippel, Thomke, & Sonnack, 1999). As a consequence there is a tendency of firms to underestimate the importance of these activities (Arrow, 1962a; Nelson, 1971). In light of the profit motive of companies, some perspective on the future i.e. the expectation of a return from innovation is needed to engage in innovation in the first place. Empirical research shows that market opportunity, technological opportunity, and appropriability of the return are key factors in R&D investment decisions as they provide a cue to the economic return expected from the activity (Jaffe et al., 2003).

2.1.5 Evolutionary perspectives in innovation studies

Evolutionary perspectives in innovation studies emerged as an alternative to neoclassical equilibrium models. They are based on the Schumpeterian doctrine of continuously changing societies and reassert the role of micro level and industry level studies of innovation (Freeman, 1994).

Evolutionary perspectives assume *bounded rationality* of these actors as they possess limited access to information and limited capacity to process it (March & Simon, 1958; Simon, 1965). That means rather than optimizing and taking decisions that maximize personal utility, actors *satisfice* and take decisions that are sufficient and satisfactory given their limitations in terms of knowledge and understanding. Decision-making is guided by shortcuts, routines, norms, rules, and the knowledge of past experience (Nelson & Winter, 1982). A consequence of this is the emergence of *path dependence.* Because actors use the status quo and existing knowledge in their decision making, the development of the future is influenced by the past (Garud & Karnøe, 2001). Furthermore, learning and the accumulation of knowledge play an important role in evolutionary approaches. Through learning actors seek to improve their decision-making as they develop better behaviors and coping strategies. Spillover is thereby, however, no externality or market failure, but a testimony to the complexity and interrelatedness of knowledge (Dosi & Nelson, 1994).

Innovation and technological change are in evolutionary economics investigated as a process over time. Change on a macro scale is explained through the cumulated of the behavior of microeconomic actors (Dosi & Nelson, 1994). The dynamics and pathways of the transition process are more important than the outright comparison of two states (Dosi & Nelson, 1994). Evolutionary economics often borrows from evolutionary theory in biology. An example of this is Nelson and Winter's 1982 phase model of technological innovation that uses the metaphor of variation, selection and stabilization to describe technological evolution (Nelson & Winter, 1982). Change does hence not lead to a pre-determined equilibrium state, but is an open-ended evolutionary process that is shaped by the past.

2.2 Three perspectives to study the effect of Energiewende on innovation

2.2.1 Multi-level perspective in sustainability transitions research

2.2.1.1 Assumptions and core concepts

Sustainability transitions research is an interdisciplinary approach to study the dynamics of transitions towards a more sustainable society. In recent years the interest in studying such transitions has surged as exemplified by an increased number of publications and academic journals devoted to the topic (Grin, Rotmans, & Schot, 2010; Markard et al., 2012; Van den Bergh, Truffer, & Kallis, 2011). Sustainability transitions research stands in the tradition of evolutionary economics and shares a lot of the same basic assumptions such as the bounded rationality of actors and the conviction that society is continually changing. It has built on and further developed important concepts from evolutionary economics such as cognitive frameworks, technological paradigms and technological regimes (Dosi, 1982; Geels, 2002, 2004; Nelson & Winter, 1982).

Sustainability transitions research is rooted in the conviction that environmental and social problems are side-effects of a modern, industrial society. They are deeply embedded in the way economy and society function and need to be regarded comprehensively and in their context in order to be adequately addressed (Grin et al., 2010). The remedy means a full transformation of a current socio-technical system incl. infrastructure and patterns of supply and demand in e.g., the energy, agriculture and transport sectors. Change does not come easy; due to historic technological trajectories and path dependence we are locked into the current system of dominant technologies, sunk investments in infrastructure, political and economic institutions and habitual lifestyles. While socio-technical systems are in principal dynamic and can change, the various linkages and interdependencies among the nodes in a system exhibit a high resilience towards change. In a stable system change tends to be incremental and directed only at improving the system, hence reinforcing it instead of breaking it down (Geels, 2002, 2004).

The notion of a system, often referred to as *socio-technical system,* is core in the sustainability transitions literature. It is the current socio-technical system that needs to change in order to get to a more sustainable future state. A socio-technical system is defined in an abstract, functional way as the combination of elements needed to fulfill a certain societal function. A societal function usually equals as a particular sector of the economy, such as energy, transport or water. The system comprises everything that is needed to fulfill this function from the supply to the demand side (Geels, 2004). Elements of the system include actors (governments, companies, individuals), institutions (laws, norms, regulations), material artifacts (physical assets, infrastructure, networks) and knowledge (tangible, intangible). These elements are closely linked and interdependent. This definition explicitly encompasses producers as well as users of technology (Geels, 2004). The term socio-technical also captures the social dimension of technological innovation. Transitions require not only a change of technology, but changes to the way that technology is used (Markard et al., 2012).

The two defining terms, sustainability and transitions, are rather broad concepts. *Sustainability* refers to the understanding suggested by the Brundtland commission where sustainable development is the endeavor to meet "the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland et al., 1987, p. 41). This encompasses foremost environmental, but also social aspects. Views on what constitutes sustainability can, however, vary and are expected to change over time (Garud, Gehman, & Karnøe, 2010). The term *transition* exemplifies the fundamental changes that are required throughout the system to achieve sustainability. Changes are far-reaching and concern all elements of the system. They may take several decades to unfold. A sustainability transition is hence a long, open-ended, and comprehensive change process. Sustainability of production and consumption is the ambition and provides a general sense of direction, but the transition has no pre-determined final state. The term *system innovation* is often used interchangeably with sustainability transition. System innovation means renewal of a socio-technical system and is hence largely synonymous. However, the term transition stresses the process nature of change, which is why it has emerged as the preferred term in the literature (Augenstein, 2015, p. 60).

2.2.1.2 Alternative approaches in sustainability transitions research

A couple of approaches have become well established and widely used in sustainability transitions research: the multi-level perspective, strategic niche management and transition management, and technological innovation systems (Markard et al., 2012; Van den Bergh et al., 2011). It should be noted that these approaches are heavily interlinked and share similar assumptions, concepts and contributing authors. They are most usefully distinguished in the way they are applied. The multi-level perspective (MLP) and technology innovation systems

(TIS) build overarching heuristics to analyze transitions. In contrast to that strategic niche management (SNM) and transition management (TM) look at transitions from a governance perspective and device a set of guiding principles and policy recommendations for the management of transition processes. They are not policy instruments in a traditional sense, but additional ways of thinking about the role of governance in sustainability transitions (Voß, Bauknecht, & Kemp, 2006).

While all approaches have their merits and therefore their rightful place in sustainability transitions research, the MLP is best suited for the research interest in this thesis. The MLP provides a framework for the investigation of transition processes from a systemic perspective. SNM, TM and TIS are fundamentally governance approaches that focus on procedure and process design in public policy and do not lend themselves to the research question of assessing an effect of a transition on innovation. Therefore, before focusing on the MLP (section 2.2.1.2.4), the other approaches are summarized below for the sake providing a comprehensive overview of sustainability transitions research.

2.2.1.2.1 *Strategic niche management*

Strategic niche management (SNM) is particularly concerned with the creation and governance of strategic niches. Proponents of the approach argue that new technologies require a shielded space where they can evolve through experiments. These experiments explore technological possibilities, but also the application and implementation of technology in society. Consumer needs are part of the experiments as are technological properties and production processes. These experiments trigger an open-ended search and learning process around all socio-technical aspects of a new technology and may lead to changes in the way that technology is designed or used (Hoogma, Kemp, Schot, & Truffer, 2002; Kemp, Schot, & Hoogma, 1998; Markard et al., 2012). The niche hence enables social learning, the development of expectations and visions and the building of actor networks (Augenstein, 2015, p. 100). SNM offers governments advice on how to use niches for socio-technical exploration. In contrast to other governmental technology strategies, SNM stresses the inclusion of user preferences and rejects pure technology-push ideas. It recommends government-funded pilot and demonstration projects with a focus on open-ended exploration, involving all relevant societal actors, making interactions transparent and anticipating a strategy for up-scaling the niches as well as obstacles that then need to be overcome (Hoogma et al., 2002). SNM is an interesting concept with elements that recall management literature on infant industry protection and clusters (Porter & Stern, 2001; Westphal, 1982), the practicality of SNM remains limited as policy recommendations are rather abstract and with the exclusive focus on niches address only one aspect of sustainability transitions. In so far it can enrich policy debates on how to best design support schemes for technological exploration activities, but not replace other innovation and environmental policy instruments.

2.2.1.2.2 *Transition management*

Transition management (TM) takes a broader and more comprehensive approach to the management of transition processes by combining concepts from socio-technical transitions with complex systems theory and the literature on governance. TM was developed in a practical context through a joint project of researchers with a Dutch national ministry with the aim to develop a process for integrating sustainability into Dutch policy-making. To this end TM proposes a cyclical process: establishing a transitions arena with a broad variety of stakeholders, developing a shared vision, defining paths towards achieving this vision, setting up experiments that can help realizing certain paths and continuously monitoring, evaluating and improving the transitions process (Loorbach, 2010). TM hence provides a practical and action-oriented framework for influencing transitions towards sustainability (Markard et al., 2012). It stresses the long-term, evolutionary and iterative nature of transition processes and emphasizes that governance needs to be reflective of all developments in order to be able to successfully shape a transition (Voß, Smith, & Grin, 2009). TM does not address other mechanisms of transition such as e.g., niche-regime dynamics (Augenstein, 2015, p. 104). Despite its development in a practical context, TM has been of limited use in policy-making. Experience from the application of the framework in the transition of the Dutch energy sector has shown that issues, which are not explicitly addressed in the theoretical framework, can impede its usefulness in practice. Such issues concern political realities of asymmetric power relationships, e.g., between actors of the established regime and niche actors, or political struggle that can lead to a dilution of sustainability targets, or the neglect of long-term strategies in favor of short-term instruments (Kern & Howlett, 2009; Kern & Smith, 2008). So, to a certain extent what applies to SNM also applies to TM, while it can enrich the political process the usefulness and practicality of its application still need to be discerned or the TM adjusted in such a way that it becomes robust in the light of the issues mentioned (Voß et al., 2009).

2.2.1.2.3 *Technological innovation systems*

Technological innovation systems (TIS) is another approach in sustainability transition research. The TIS literature looks at transition processes through socio-technical systems and aims to understand why and how sustainable technologies penetrate such systems. In the definition of TIS, socio-technical systems are dynamic networks of agents in a particular sector or industry and in the context of a given institutional infrastructure. These actors drive the development, implementation and utilization of a technology. Through an analysis of the interactions between these agents, barriers to the diffusion of the technology are identified. Institutions are of special importance as they influence the interaction between agents and hence the functioning of the innovation system (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008). Ultimately, the objective of TIS is to inform policy making (Markard et al., 2012). TIS has made important contributions to the collective understanding of innovation systems, including the identification of certain processes in innovation systems that need to run well for the system to be successful, and the enhanced understanding of market failures through a focus on actor networks (Bergek et al., 2008). Fundamentally, however, TIS does not address structural change as it is only focused on technological diffusion within a network of actors (Geels, 2010). It does not offer a suitable perspective to investigate the research interest of this thesis.

2.2.1.2.4 *The multi-level perspective*

The *multi-level perspective* (MLP) is an analytical framework to study changes in a socio-technical system on three levels: landscape, regime and niche. Investigating the interaction between these three levels it aims to identify and describe patterns and mechanisms through which transition processes occur. It was developed by Frank W. Geels and others (Geels, 2002; Rip & Kemp, 1998) and combines learnings from evolutionary economics (Dosi, 1982; Nelson & Winter, 1982), technology studies (Hughes, 1987), institutional economics (North, 1990), and sociology (Giddens, 1984). It has mainly been used to explain historical transitions (Geels, 2002), however, is increasingly being employed in the study of current and ongoing transitions as well (Augenstein, 2015; Geels, 2012; Kern, 2012; Van der Vleuten & Högselius, 2012).

The *socio-technical regime* forms the core concept of the MLP. A regime is a set of rules that govern the behavior of actors in a socio-technical system. The concept of regime is very similar to the definition of institutions as "rules of the game" (North, 1990) in new institutional economics. A regime combines various types of rules as diverse as formal laws and regulations, behavioral routines and standards, societal norms and biases, political paradigms, and shared beliefs and values. The difference is that a regime is defined with respect to a particular socio-economic system. A regime is the "deep structure" (Geels, 2011, p. 31) or implicit logic that determines the stability of that system and directs its development in a certain way. Rules are manifested in the cognition of actors and embedded in all other tangible and intangible system elements (Geels, 2004). While a regime is not material per se, the representation and reproduction of the rules of the regime in the material artifacts of the system reinforces its strength. Geels distinguishes seven dimensions in a regime: technology, user practices and markets, symbolic meanings of technology, infrastructure, industry structure, policy and techno-scientific knowledge (2002, p. 1262). Regimes are characterized by path-dependence and technology lock-ins that render them highly stable and persistent over time. Incremental innovations and improvements in line with the regime shape technological trajectories that reproduce the basic tenets of the regime (Geels, 2002). Regimes are, however, not static, but subject to change due to internal and external developments. Rules in a regime are semi-coherent; while their broad alignment gives the regime stability, there can also be discrepancy between rules of different subsystems, creating the opportunity for tension and change to the regime from within (Geels, 2004). In addition, change can also come from the two adjacent levels, landscape and niches.

The *socio-technical landscape* is the wider macro environment surrounding a regime. It captures elements of society that cannot be directly influenced by actors and are hence even harder to change than regimes. This includes culture, fundamental values and beliefs, but also material assets such as large networks of infrastructure or spatial and natural conditions. It also comprises other non-technological and very diverse factors such as global commodity prices, demographic change or political and economic turmoil. Landscapes do change, but much slower than regimes. On the other side, landscape events can trigger regime changes (Geels, 2002; Geels & Schot, 2007).

Lastly, *niches* constitute the micro level and major source of novelties in the MLP. Niches develop innovations that are radical and challenge the basic rules of a regime. New technology emerges in niches, where it is shielded from competition and market forces. Niches are important as they enable learning processes through developing a technology, using and applying it and studying its performance and side effects. Niches also foster actor networks surrounding a technology (Geels, 2002). Examples of niches include exploratory corporate laboratories, university research centers, or military institutions that operate distinct from ordinary, regime-compliant science institutes.

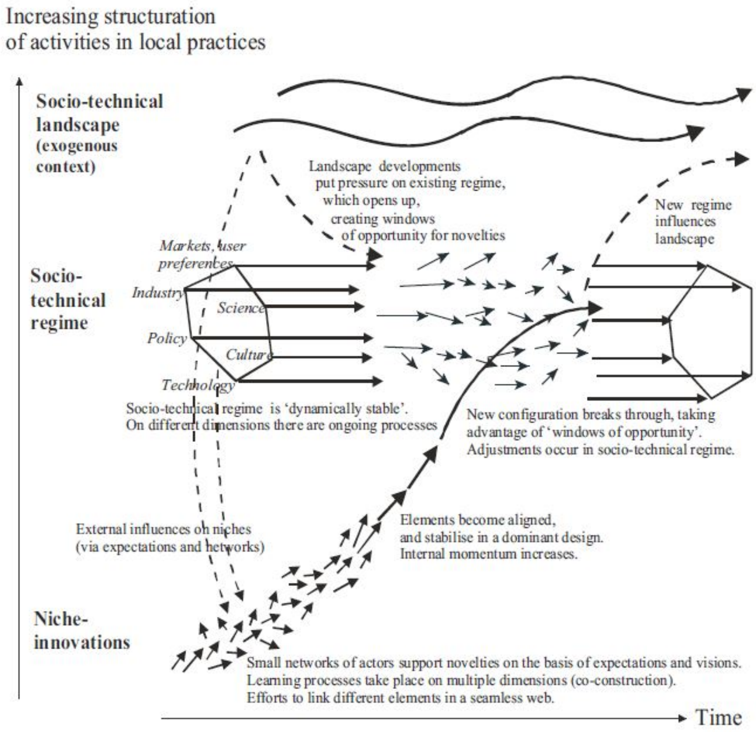
The degree of structuration, and with it resistance to change, increases with the levels. Niches are the most dynamic and less stable level, while landscapes are the most stable, and regimes are somewhere in-between. A transition is characterized by interaction of these three levels in a dynamic way: niche innovations build momentum and break into established regimes, landscape developments destabilize regimes and create windows of opportunity for technological niches, regimes can destabilize from the inside through divergence of the rules of their constituting social groups. By focusing on reiterative action the MLP rejects the idea of linear causality and replaces it with "processes at multiple levels that influence and reinforce each other" (Geels, 2011, p. 29). A successful transition is marked by a complete regime shift that occurs because of the "alignment of developments" on all levels (Kemp, Rip, & Schot, 2001). Recent theoretical literature on the MLP has emphasized that levels do not represent a hierarchy in terms of more or less important for transition, but only represent different levels of structuration and predisposition for change (Geels, 2011).

2.2.1.3 Transitions in the multi-level perspective

Empirical work using the MLP is usually directed at the dynamics between the levels and the identification of transition mechanisms. Transition mechanisms are varied by nature of the change within the different levels and the interplay between them.

On a basic level, Geels and Kemp (2007) define a *transition* as a dynamic process of change across all three levels where a socio-technical systems is changed through landscape pressures, weakening of the established and emergence of a new regime, and the diffusion of niche innovations, see Figure 3. The transition is completed when a new regime has emerged.

Figure 3: Multi-level perspective on transitions



Source: Geels, 2011, p. 28

Building on this, Geels and Schot (2007) develop a typology of four transition pathways by varying the nature (i.e. extent of disruption) and timing of change dynamics across the levels. A *transformation*[1] *pathway* combines moderate landscape pressure with premature niche innovations and leads to regime actors modifying the regime and thus changing the overall trajectory. In a *de-alignment and re-alignment pathway* landscape pressure disrupts the regime and enables niche innovations to emerge and successfully establish in a new regime. In a *technological substitution pathway* landscape pressure also disrupts the regime as niche innovations are already successful and hence replace the technology to form a new regime. In a *reconfiguration pathway* niche innovations are symbiotic to technology in an established regime and are hence integrated into the regime by regime actors. However, the accumulation of innovations leads to regime change (Geels & Schot, 2007, p. 406 ff). In addition, transition patterns have been identified as smaller units that describe small parts or short time spans of a transition and the dynamics on or between levels. Taken together they make up distinct transitions pathways. As such, patterns detail the

[1] In this thesis transition and transformation are in general used synonymously and not distinguished in the way proposed here by Geels and Schot (2007).

mechanisms and multi-level dynamics of transitions. Patterns include for example add-on and hybridization as new technology is integrated into existing technology (Geels, 2005) or hype-disappointment cycles where initial enthusiasm for a technological improvement is followed by a sudden loss of interest (Verbong, Geels, & Raven, 2008). The authors stress that mechanisms as well as patterns constitute ideal-type dynamics that may in reality overlap or be combined.

Essentially, it is the interaction between the niche, regime and landscape levels as well as the dynamics within each of these levels that determine transition processes. The dynamics between niche and regime are most often studied. Since the landscape with its high degree of structuration is a given i.e. cannot be influenced by individual actors, it is especially the interaction between niche and regime, and the influence of landscape developments on both, that can be studied. Furthermore change is often initiated in niches and niche innovations provide the range of options that change can take. Dynamics emerge around the timing of niche innovation and the modes of penetration of an existing regime with respect to regime-internal dynamics and landscape events, e.g., the extent of disruption that a niche innovation causes and the behavior of niche and regime actors in the process. Smith (2007) identifies various processes of translation and interaction between niche and a regime: First, a niche comes into existence in direct opposition to a regime hence building on regime language and turning it into its opposite. Second, the regime takes up criticism from the niche and adjusts, at least regarding language. Third, the niche adapts in a way that it better fits into a regime. This does not mean that it regresses from its transformative ambition or loses its substantive focus, but in order to realize its full potential it needs to be able to fit into regime practices, e.g., in the form of add-ons. Fourth, niche and regime can adapt mutually through join projects and collaboration.

Another dynamic of change is that between several systems and regimes. Systems and regimes do not exist in isolation, but are connected through actors that stretch over more than one regime and may be affected by the same landscape and niche developments. Change dynamics can hence influence the relative position of regimes or redefine regime boundaries. Furthermore regimes can compete with each other, change together in a mutually beneficial way, reconfigure their constitution or influence dynamics in the respective other regime (Raven & Verbong, 2007).

Furthermore, there are always regime-internal dynamics. Because a regime is made up of heterogeneous actors with diverging interests that are bound together by "semi-coherent" rule sets, often establishing distinct sub-regimes, regimes are always in fluctuation, or can only be considered "dynamically stable" (Geels & Schot, 2007, p. 406). Tensions or even "cracks" in regimes force them to open up and eventually change due to landscape pressures, internal problems or niche innovations (Geels, Kemp, Dudley, & Lyons, 2012). Furthermore, regimes can themselves be drivers of radical change (Bosman, Loorbach, Frantzeskaki, & Pistorius, 2014; Van der Vleuten & Högselius, 2012).

It is important to note that change according to the MLP is always co-evolutionary (Geels, 2004). This means that the development of different elements of a system, structural entities, actors or levels, is interrelated and interdependent. Different elements evolve together and influence each other in a complex, iterative way. "There is not just one kind of dynamic […], but multiple dynamics which interact" (Geels, 2004, p. 909). The notion of co-evolution rejects simple causality where an action triggers a reaction as a one-off occurrence and in isolation of contextual factors. This conviction is the reason why the MLP puts an emphasis on process, mechanism and patterns, rather than formal models with precise, computable outcomes (Geels, 2010)

2.2.1.4 Contributions and criticism

Despite its popularity, the MLP is also subject to criticism of its ontological foundations as well as its application. However, the criticisms point the way to expanding and improving this research approach. First, the MLP can tend to be structuralistic and underplay the role of actors and agency in transition processes. Applying structural models like the MLP's three levels to real life problems can feel like imposing a rigid structure that does not leave room for investigations of autonomous actor behavior (Smith, Voß, & Grin, 2010). However, Geels argues that the three levels only constitute a "stylized representation" of the MLP and do not capture all of its aspects and analytical possibilities (Geels, 2011, p. 29). Indeed, the ontological foundations of the MLP emphasize the duality of structure and agency and hold that both are of equal importance for social change (Giddens, 1984). Structures only exist because they are continuously reproduced and enacted by individuals and social groups (Geels, 2011; Geels & Schot, 2007). While structures constrain the activities of actors, they also enable them. Actors can take creative actions and shape and change their structures from within. In addition, while most empirical studies using the MLP do apply the three levels, the MLP does not preclude the analysis of actors and the focus on agency. Especially when investigating niche-regime and landscape-regime dynamics a focus on actors drawing on adjacent literature and principles of agency may be insightful. Indeed, it may only be possible to understand the important role of actors in transformation processes by investigating their strategic behavior and positioning with respect to their surrounding structures (Augenstein, 2015, p. 76). Thus the development of research in the tradition of the MLP that explicitly deals with agency is highly encouraged (Geels, 2011).

Second, due to the critical importance of technological niches, studies applying the MLP are prone to a bottom-up bias that stresses the role of niches over regime-internal changes and landscape effects. Investigating the struggle of niche innovations against established regimes is frequent especially in early empirical contributions to the literature (Geels, 2011). This follows the narrative of many contributions in innovation studies as well as environmental studies that phrase change in general and sustainability transitions in particular as a fight of David against Goliath (Baumol, 1988; Hajer, 2005). However, this is not an inherent limitation of the MLP, but rather a state of research that can and should be expanded. The typology of transition pathways (Geels & Schot, 2007) explained above (section 2.2.1.3) already suggests that transitions can be triggered by several combinations of landscape events and niche innovations.

Third, the MLP seems to be more suitable to ex-post analyses of historical transitions than to studying current and ongoing change processes. It is comparatively easy to study transitions in retrospect when start and end points are known and it is clearly established how the dynamics have played out over time. This is why the MLP is often demonstrated with case studies of historical transitions, e.g., from sailing to steam ships (Geels, 2002) or from horse-drawn carriages to automobiles (Geels, 2005). Investigations of transitions "in the making" do also exist, but are less frequent. As a heuristic framework that employs a process-based explanatory style the MLP has little predictive power (Geels, 2011). The MLP is a "middle range theory" (Merton, 1968, p. 39) that builds analytical models through the empirical research of concrete phenomena in a specified context. It does not seek to explain universal concepts such as "society" or "capitalism" (Geels, 2007). While its specifications go beyond the mere statement of facts to relate phenomena with one another, it cannot make predictions. The MLP provides a perspective for looking at things and a terminology to describe and interpret them rather than a mathematical formula that predicts future outcomes. It is evident from the studies of ongoing transformations that they rarely employ the three-level framework as is, but instead narrow the research scope and focus on smaller aspects of it. They investigate e.g., fixed (past) time spans, specific patterns and mechanisms of transition, and do not aim to provide a full explanation of the entire transition process (Augenstein, 2015; Geels, 2012; Kern, 2012; Van der Vleuten & Högselius, 2012).

2.2.2 Environmental economics

2.2.2.1 Assumptions and core concepts

Environmental economics studies market failures in the context of environmental problems. The focus on environmental innovation is a particular subset of environmental economics that is closely related with innovation economics. The study of the effect and effectiveness of environmental policy for innovation is an integral part of the research field and the literature has developed important insights into the effect of environmental policy instruments for innovation.

The core contention in environmental economics is that innovation conducive to preserving the environment suffers from a double market failure (Jaffe, Newell, & Stavins, 2005). The first market failure is the one observed for all innovation activities (cf. section 2.1.2). The positive externalities of knowledge spillovers mean that private firm who invest in an innovation cannot appropriate all the benefits. Social benefits from innovation will always be larger than private benefits. This causes underinvestment in such innovation compared to what would be optimal from a social point of view. The second market failure is specific to all environmental problems. Economic activity results in negative externalities for the environment such as pollution, the depletion of natural resources, or climate change, which are not sufficiently reflected in the value of the market transaction (Baumol, 1988).

2.2.2.2 Environmental policy and innovation

The environmental economics literature suggests that environmental policy can address this double market failure through public policy. A key concern in environmental economics is therefore to identify the best policy instrument to achieve environmental innovation. Researchers have classified and evaluated different types of policy instruments to this end (Del Río González, 2009; Horbach, 2008; Kemp & Pontoglio, 2011). In addition to the distinction between technology-push, demand-pull and systemic instruments in innovation policy, which is based on the purpose of the policy in terms of the innovation value chain policies, environmental policy has its own distinction of policy instruments. Environmental policy distinguishes types of policy instruments based on how they seek to induce pro-environmental behavior: market-based, through command-and-control regulation, or through information. A combination of the two approaches results in a matrix typology in which policy instruments are clustered according to their type in terms of environmental policy and purpose in terms of innovation policy, as depicted in Table 2.

Table 2: Type-purpose instrument typology with selected examples

Purpose in terms of innovation policy: / Type in terms of environmental policy:	Technology-push	Demand-pull	Systemic
Market-based	R&D support	Subsidies, feed-in tarifs, tradable permits, taxes	Tax reforms, infrastructure provision
Command-and-control	Patent law, intellectual property rights	Standards, limits, prohibitions	Market design, electricity grid access
Information	Vocational training	Labels, information campaigns	Education system

Source: Adapted from Rogge & Reichardt (2013).

Just as the dichotomy between technology-push and demand-pull in innovation policy, environmental policy has a dichotomy between command-and-control and market-based instruments. Command-and-control instruments refer to classical, regulatory policy that prescribes standards or limits for something that is environmentally harmful, monitors compliance and penalizes breaches. Market-based instruments seek to use market forces to remedy innovation or environmental problems by making the externalities part of the market transaction. Market-based policies geared at the adoption and diffusion of a particular technology are also called deployment policies (Klessmann, Held, Rathmann, & Ragwitz, 2011). Sometimes a further distinction between price-based policies and quantity-based policies is made. In price-based policies the regulator sets a price and lets the market determine the quantity. Examples for these are environmental taxes or feed-in-tariffs for renewable energy. In quantity-based policies the regulator sets the quantity and lets the market find the adequate price. Examples are tradable permits for emissions, or quotas for renewable energy. There is no universal consensus on how to best classify environmental policy instruments for the purpose of innovation and several more categorization systems exist (Rogge & Reichardt, 2013). In addition to the existence of such policy instruments, their design features have also been related to their effectiveness in influencing innovation. Most research has been carried out on stringency (Frondel, Horbach, & Rennings, 2007; Johnstone & Haščič, 2013; Martin, Muûls, & Wagner, 2011; Rogge, Schneider, & Hoffmann, 2011; T.

S. Schmidt, Schneider, Rogge, Schuetz, & Hoffmann, 2012), but various other factors including credibility and predictability have been found important (Engau & Hoffmann, 2011; Johnstone, Haščič, & Kalamova, 2011; Kemp & Pontoglio, 2011; Vollebergh, 2007). The environmental economics literature today agrees in the sense that it is the total effect of a policy mix, rather than individual aspects that is important.

2.2.3 Organization and management studies

2.2.3.1 Assumptions and core concepts

Organization and management studies share many epistemological foundations and influences with evolutionary economics, however, the locus of research differs. While evolutionary economics is interested in understanding and explaining the macro and meso levels of technological change through micro actors, organization and management studies look at the micro level exclusively and moreover add a firm-internal view to innovation studies. It often seeks to give practical advice to companies and managers, rather than explain technological and other economic change over time. Just like evolutionary economics, scholars in management and organization studies typically embrace bounded rationality as the guiding principle for individual decision-making in organizations (March and Simon 1985). In doing so, they also acknowledge the role of routine behavior, path dependence and the importance of organizational learning. In the process of socio-technical change firms have a dual role. They are themselves actors in the innovation process and hence contribute to change, but they are also affected by innovation and change taking place in their business environment.

Organizational scholars are particularly interested in the nature of learning on the firm level. Based on March (1991) two modes of learning are typically distinguished: exploitation and exploration. *Exploitation* builds on existing knowledge through "refinement, choice, production, efficiency, selection, implementation, execution"; *exploration* develops new knowledge through "search, variation, risk taking, play, experimentation, play, flexibility, discovery, innovation" (March, 1991, p. 71). Although there is a certain degree of trade-off between the two since they compete for scarce organizational resources, firms need to engage in both and they are mutually enabling in the long run (Farjoun, 2010; Hoppmann, Peters, Schneider, & Hoffmann, 2013; Lavie, Stettner, & Tushman, 2010).

2.2.3.2 Technological change and the failure of incumbent firms

Ample empirical studies have investigated how firms fare in the light of rapid technological change. This research shows that there is a marked difference between incumbent firms i.e. firms long established in their industry, and start-up firms, i.e. new entrants in a particular industry. In the light of *technological change* incumbent firms often fail and yield the playing field to start-up firms (Christensen & Bower, 1996; Henderson & Clark, 1990; Tripsas & Gavetti, 2000; Tushman & Anderson, 1986; Tushman & O'Reilly, 1996). This is especially pronounced if the change occurring is *radical or discontinuous* i.e. constitutes a technological breakthrough that punctuates a previous period of incremental change, if it is *architectural* i.e. does not primarily affect technological properties as such, but rather the way that different components interact with each other (Henderson & Clark, 1990), or if implementation of the change requires organizational adjustments on a wider scale leading to the renewal of the *business model* of the firm (Chesbrough & Rosenbloom, 2002). Three different explanations for the failure of firms in light of such change can be found: economic disincentives on part of the incumbent to engage with new technologies, structural reasons due to the embeddedness of incumbents in a certain strategic direction and value network, and organizational inertia as the result of resources, capabilities and cognition (C. W. Hill & Rothaermel, 2003).

First, economic explanations suggest that incumbent firms face an economic disincentive to act because they want to protect existing revenue streams and avoid the cannibalization of their successful products (C. W. Hill & Rothaermel, 2003). Incumbents tend to invest in incremental innovations to their existing products in order to strengthen their revenue base. They avoid the technological uncertainty of more radical innovation. They also deliberately choose to not invest in radical innovation in order to not promote it further. Lacking established business, start-up firms do not face such pressures, but instead are incentivized to promote radical innovations as due to barriers to entry they are not able to compete with incumbents in their established business areas (Henderson, 1993).

Second, structural explanations focus on commitments that incumbent firms have towards their suppliers, customers, investors, complementary product providers and communities i.e. their *value network* (C. W. Hill & Rothaermel, 2003). Network commitments provide for inflexibility in the light of change as the logic to serve the existing value network trumps the exploration of new, disruptive opportunities (Christensen & Bower, 1996; Christensen & Rosenbloom, 1995). Incumbent firms fail when the commitments to their established value network causes them to ignore small, but fast growing markets, that eventually overtake the dominant position (Christensen & Bower, 1996).

Third, organizational explanations analyze the failure of incumbent firms in the light of organizational characteristics (C. W. Hill & Rothaermel, 2003). As organizations and the individuals within them are boundedly rational, they develop highly structured routines in order to take decisions and coordinate their activities (Arrow, 1962b; March & Simon, 1958; Nelson & Winter, 1974; Simon, 1979). These routines are what make organizations work in the first place as individual activities are directed towards a joint objective. Moreover, they define the competitive advantage of organizations. *Core capabilities* or *core competences*[1] embody the collective knowledge of an organization in terms of a combination of resources and skills and hence distinguish organizations in the market place. They constitute what firms are good at (Prahalad & Hamel, 1990). Incumbents struggle if they are faced with change that destroys the value of these competences (Tushman & Anderson, 1986). They are also more likely to pursue activities that build on their existing competences. This means that the technological exploration a firm engages in is constraint by these organizational determinants (Dosi, 1982). If capabilities prevent change, they can become *core rigidities* (Leonard-Barton, 1992) which threaten corporate survival. Established power structures around such core competences may further inhibit change and aggravate this (Cyert & March, 1963).

Related to capabilities are investigations that look at the cognition of an organization and of the individuals within it. Cognitive explanations start even earlier in the innovation process than the ones based on capabilities. Cognition influences how organizations notice, interpret and react to changes in their external environment (Weick, 1979). They direct and constrain learning efforts within organizations and thus determine which organizational capabilities develop in the first place (Tripsas & Gavetti, 2000). Cognitive representations of decision-makers within firms shapes strategic choice (Barr, 1998) and can determine the technological trajectory that an organization takes. Cognitive representations are especially influential in early stages of innovation when economic effects cannot yet be discerned (Kaplan & Tripsas, 2008). Cognition is manifested on the individual as well as the organizational level. Organizations operate with a *dominant logic*, i.e. a set of rules, norms and beliefs that prescribes what is considered right for the organization (Prahalad & Bettis, 1986). Firms can fail when the cognitive representations of their decision-makers restrict

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[1] The terms *capability* and *competence* are used synonymously in this thesis.

them in developing or utilizing capabilities that later turn out to be critical in a new environment (Tripsas & Gavetti, 2000). Often such cognitive representations are shared in an industry providing for a homogenous macroculture and industry-wide barriers to change in that industry (Abrahamson & Fombrun, 1994; DiMaggio & Powell, 1983).

Cross-cutting economic, structural and organizational explanations, the literature on business models provides yet another perspective on the failure of incumbent firms. A *business model* is a multi-dimensional concept that describes how a firm creates and captures value. Chesbrough and Rosenbloom (2002) define a business model as the combination of a firm's target market, value proposition, value chain, cost and profit function, value network, and competitive strategy. A successful business model shapes the dominant cognitive logic within a firm and constrains the firm's exploratory activities to those that fit the established business model. Opportunities that require a new and adjusted business model are hence foregone, either because they are not identified in the first place, or because they are not implemented. Firms fail if alternative business models turn out to be more successful.

2.2.3.3 Strategies to promote organizational learning

However, not all incumbents fail. Many incumbent firms do survive or even promote radical innovation from within their firm (C. W. Hill & Rothaermel, 2003). "The picture which […] emerges from numerous studies of innovation in firms is one of continuous interactive learning" (Freeman, 1994, p. 470). Effective strategies for promoting such learning are key to this. Building on the exploitation/exploration distinction of March (1991), the ability to obtain new sources of competitive advantage despite path dependencies has also been called *dynamic capabilities* (Eisenhardt & Martin, 2000; Teece, Pisano, & Shuen, 1997). Two of such dynamic capabilities are of particular importance for organizational learning: First, the ability to manage the balance between exploration and exploitation and engage in both simultaneously, called *ambidexterity* (O'Reilly & Tushman, 2008, 2013; Tushman & O'Reilly, 1996). Second, the ability to be inspired from the business environment rather than internal factors, coined *absorptive capacity* (Cohen & Levinthal, 1990). The level of absorptive capacity in a firm is typically associated with previous knowledge investments of that firm (ibid.).

Several strategies that that firms can use to promote organizational learning have been identified. These strategies apply to incumbent as well as to start-up firms. In effect, some of the strategies are meant to promote the entrepreneurship that is supposed to be found in start-up firms and install it in incumbents.

First, leadership on the strategic as well as the organizational level is important. On the strategic level middle and senior managers need to have the foresight to navigate their organizations between continuous and discontinuous change, on the organizational level they need to steer learning processes in such a way that firms are successful in their current business, but at the same time remain open to explore new opportunities (Chesbrough, 2010; Christensen & Bower, 1996; Tushman & O'Reilly, 1996).

Second, firms benefit from having an organizational culture that promotes entrepreneurial attributes such as autonomous action, experimentation, knowledge sharing, rapid implementation, and tolerance of failure (O'Reilly & Tushman, 2008; Tushman & O'Reilly, 1996).

Third, the continuous engagement in experimentation and the implementation of new ideas in order to get acquainted with novelties and test them is perceived critical. This includes investments in basic research and the development of technical capabilities even if they are not directly related to current business (C. W. Hill & Rothaermel, 2003; Tripsas, 1997) as well as the implementation or "effectuation" of new things, that is putting them into action in order to test them (Chesbrough, 2010, p. 360)

Fourth, the organizational structure can promote organizational learning by being flat and non-hierarchical in order to promote the desirable entrepreneurial culture. Moreover, it has been shown that the organizational separation of teams or departments that work on something very new is beneficial (Christensen & Bower, 1996; C. W. Hill & Rothaermel, 2003). It is often easier to conduct especially exploratory activities separately from the rest of the organization as they may be better shielded from the dominant logic of the organization as well as from structural rules such as resource allocations processes or performance measurements (Christensen, 1997; O'Reilly & Tushman, 2008). This can even take the form of new ventures developing inside diversified firms (Burgelman, 1983)

Fifth, systematically tapping into external knowledge through collaborations, knowledge exchange and methods of open innovation can constitute an important source of organizational learning. Business clusters have long been connected to technological and economic development as they enhance productivity and innovation (Porter, 1990; Porter & Stern, 2001). Strategic alliances between start-up and incumbent firms have also been suggested as they provide learning experiences for both sides and improve the performance of incumbent firms (Rothaermel, 2001). Incumbent firms can use their complementary assets to help the commercialization and diffusion of the product suggested developed by the start-up firms start-up idea, thereby aiding start-ups with go-to-market and becoming established in the market (Rothaermel, 2001; Tripsas, 1997). However, even in strategic alliances a nuance of organizational inertia prevails: Incumbent firms tend to prefer these alliances that make use their complementary assets over alliances targeted at joint technological exploration (Rothaermel, 2001). More broadly the idea of *open innovation*, i.e. the use of internal and as well as external ideas in corporate innovation, as well as the development of internal ideas even outside of corporate boundaries, has also been suggested as an effective method for organizational learning (Chesbrough, 2003, 2006; Gassmann, Enkel, & Chesbrough, 2010). The open innovation literature very broadly suggests different types of cooperations between all kinds of actors in all stages of the innovation process (Gassmann et al., 2010).

2.3 Definition of innovation for this thesis

The introduction to some basic literature of innovation in business and economics in the preceding sections has shown some of the various ways of looking at innovation. When it comes to defining innovation it is important to be clear about the different dimensions and the particular stance that is chosen. Diverging interpretations are a challenge for academic researchers, but also practitioners as differences of understanding typically result in differences of measures and measurements. Especially when innovation is the dependent variable of academic studies and determinants of innovation are investigated, a lot of confusion and seemingly irreconcilable empirical results in the academic literature stem from ambiguity of the innovation definition used (Hauschildt & Salomo, 2011; Rennings & Rexhäuser, 2014). In the same vein, policy makers that stipulate "innovation" as a policy objective may view this ambiguity as a blessing or a curse since an assessment of policy effectiveness in that regard will always remain controversial if no measurable targets and criteria for measurement are defined.

It follows that for this dissertation a brief discussion of various dimensions of the term and the development of a working definition of the concept of innovation are necessary. The purpose is to establish full transparency about the understanding and use of the term here. The qualification of the concept is utile to guide the empirical research and also point to limitations and areas of further study. The first aspect to clarify is the level of analysis regarding innovation. On macro and meso levels (i.e. world, nation, society, system) innovation is often used as a synonym for technological, social, or economic change. This is the understanding of innovation in much of the literature on economic growth. The opposite end is the definition of innovation on a micro level (i.e. individuals, organizations, social groups) where it is understood in terms of novelties produced at that level. This is the view taken in the organization and management literature. In evolutionary economics and innovation policy both approaches may prevail. The two levels are of course linked as the accumulation of micro level innovation leads to change on the macro level. Making this distinction clear is of particular importance in this thesis. Energiewende has been defined above as a socio-technical transformation i.e. a process of change on a macro level. This is however, only the context or backdrop of the research interest. With a focus on firms and corporate innovation, it is the micro level of innovation carried out by organizations that is relevant here.

Figure 4: Selected dimensions for defining innovation on a micro level

Dimension	**Range of definitions**				
Innovation process: which step counts?	Invention *e.g., scientific discovery*	Implementation *e.g., market launch*	Diffusion *e.g., adoption*		
Subject: what is being innovated?	Product	Process	Strategy	Organisation	Business model
Degree of novelty: how new?	New to the world	New to the organisation			
Intention: what qualifies as new?	Neutral/ positive *e.g., any novelty*	Normative *e.g., novelty with a purpose*			

Even on that micro level various dimensions for defining innovation exist (Hauschildt & Salomo, 2011; OECD & Eurostat, 2005; Swann, 2009).

Figure 4 provides an overview of some of the relevant dimensions, but is not exhaustive. First, innovation can refer to all or only single steps of the innovation process (cf.
Figure 2, p. 13). It can be used short for the first stage (invention), as well as the second stage (innovation/implementation) or the third stage (diffusion). Furthermore, innovation may be defined by the subject that is being renewed. In the realm of corporate innovation this includes products and processes, but also strategy, organization or business model of a firm.

The degree of novelty of an innovation may also be regarded. Lastly, innovation may be defined in a neutral, positivist way or with a particular sense of direction in a normative way.

This thesis employs a broad concept of innovation that focuses on the micro level. This is particularly relevant for the research of companies, and is in line with the definition adopted by the expert commission on the Energiewende monitoring process (Löschel et al., 2014c) and definitions employed by researchers who have posed similar research questions (Kemp & Pearson, 2007; Rogge, Schleich, Haussmann, Roser, & Reitze, 2011; Rogge, Schneider, et al., 2011; T. S. Schmidt et al., 2012; Voß et al., 2003). The definition goes as follows:

Innovation is the intentional and targeted invention, implementation and diffusion of a subjectively new or improved product, process, strategy, organization or business model that is perceived to be relevant in the context of Energiewende.

Five aspects of this deem further elaboration: intentional and targeted; invention, implementation and diffusion; subjectively new or improved; product, process, strategy, organization or business model; and perceived to be relevant in the context of Energiewende.

First, innovation is *intentional and targeted.* Innovation does not happen by chance, but requires deliberate and purposeful action aimed at achieving a certain objective. Firms innovate because they seek a return (cf. section 2.1.4).

Second, innovation refers to *invention, implementation and diffusion.* The innovation definition here is process-based and echoes the three stages of the innovation process as defined following Schumpeter (cf. section 2.1.1). The activities that take place as part of the process are emphasized over the final output. This also means that the process can be operationalized for empirical research with activity-based innovation indicators, as will be done later in the development of the conceptual framework (cf. section 5.2.1.). Such a process-based definition is also used by the expert commission's review of the Energiewende monitoring process who hold that innovation encompasses the invention as well as the diffusion of novelties (Löschel et al., 2014c, p. Z-21).

Third, an innovation needs to be *subjectively new or improved*. The degree of novelty of the innovation is defined here from the perspective of the innovator i.e. something that the innovating firm considers new, or better. That means an innovation does not need to be new to other firms or the world at large to qualify here. Furthermore, since the focus of this dissertation is on the innovation responses of individual firms, this definition does not infer the impact of any innovation outside of the boundaries of the firm. In that way it leaves open other degrees of novelty that are often distinguished by researchers studying industry-wide technological change such as continuous (evolutionary, incremental), discontinuous (revolutionary, radical, disruptive) or architectural (systemic) innovation (Hauschildt & Salomo, 2011, p. 12; Swann, 2009, p. 30).

Fourth, the substance of the innovation may concern *product, process, strategy, organization or business model* of the firm. While the majority of the literature on innovation and technological change is focused on product and process innovations, other types of innovation are increasingly receiving attention in the literature (OECD & Eurostat, 2005; T. Schmidt & Rammer, 2007). Product and process are the most established and well-investigated types of innovation. Product includes all goods and services that a firm plans to market. Process refers to the methods used in producing these products. Both dimensions are often associated with technological innovation, although there are non-technological possibilities of product and process innovation as well (T. Schmidt & Rammer, 2007). Furthermore, at the firm level various types of non-technological, organizational innovation may take place. Innovation here can pertain to the strategy of the firm, various attributes of the organization, or extend to business model innovation if several aspects of corporate activities are changed simultaneously (Chesbrough, 2007, 2010).

Fifth, the innovation is *perceived to be relevant in the context of Energiewende*. This element gives the definition of innovation a sense of direction. Only novelties that are intended as responses to the issue at hand are considered relevant innovations in this dissertation. Many researchers with similar research questions and cases have employed such a normative definition (Kemp & Pearson, 2007; Voß et al., 2003). If actors engage in innovation activities intentionally they must have a specific purpose in mind and the objective to develop an adequate response to a specific issue. The interpretation of both, the purpose and the adequacy of the response, are subjective (Cames, 2010). Since the aim of this dissertation is to study the innovation response of specific actors to a particular issue, it makes sense to leave it to the actors to decide which innovation activities are considered responses, and to what exactly. This normative view is also strongly emphasized in the Energiewende expert commission's concept of innovation. The expert commission states that the purpose of innovation in the context of Energiewende is to create a climate-friendly, secure and cost-efficient supply of energy in Germany. It even goes one stage further and details where such innovation might be expected along the energy technology value chain. This includes energy generation technology, technology for the distribution and usage of electricity and heating, smart grids, as well as components and materials needed for these technologies and the services necessary to support and implement them (Löschel et al., 2014c, p. Z-21).

3 Energiewende and its intended innovation effect

This chapter takes a closer look at energy transitions in general and the German energy transition in particular. The aim is to introduce the substantive subject of this thesis and elaborate how Energiewende policies seek to affect innovation.

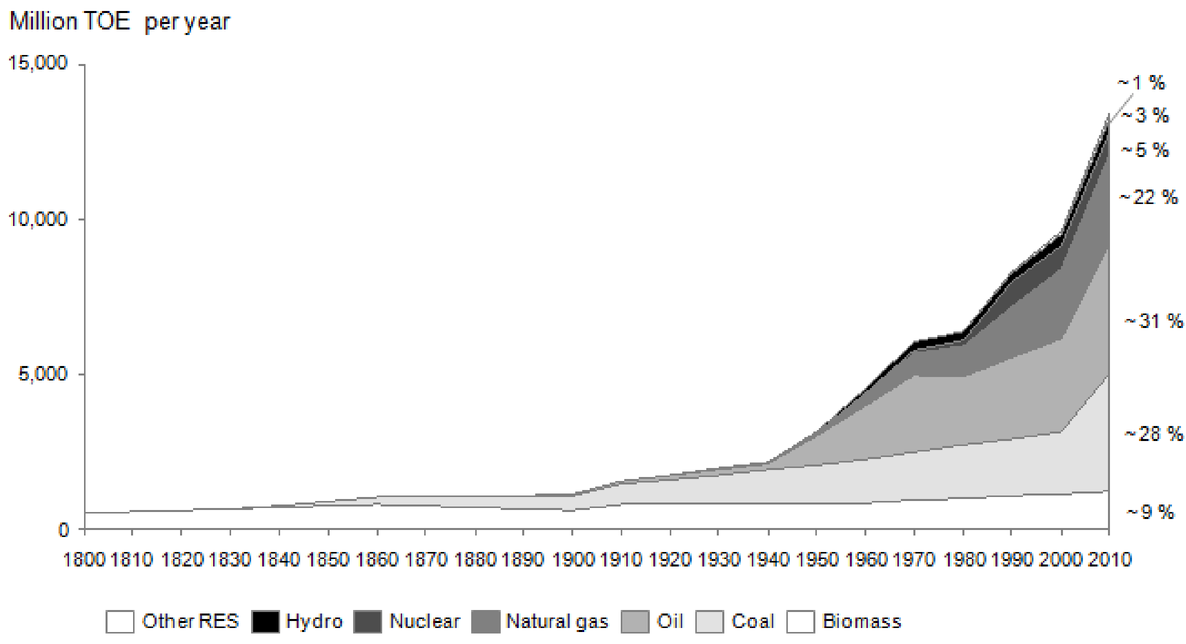
Energiewende has become the popular term to describe the transformation of Germany's national energy system through a sharp reduction of greenhouse gas emissions and a simultaneous phase-out of nuclear energy. While the term has only been widely used in public discourse since the decision to accelerate the phase-out of nuclear energy following the Fukushima accident in spring 2011 (Google Trends, 2014), its origins as well as the political process at its core reach back as far as the 1970s and 1980s (Jacobsson & Lauber, 2006). The term already suggests that it is not a one-dimensional policy instrument that affects a singular policy area, but a transformation or transition that is substantial in scale and effect. Nevertheless, Energiewende is also inextricably linked to specific laws and regulations of German energy policy, such as e.g., the *Erneuerbare Energien Gesetz* (EEG) that promotes the use of electricity from renewable energy sources (RES-E). Throughout these laws and other policy documents references to innovation are made.

This chapter is structured as follow. First, as an introduction to energy transitions in general, the reasons behind energy transitions towards sustainability as well as international differences between energy transitions are explained (section 3.1). Second, the current discourse around Energiewende is reviewed and strands of interpretations identified and synthesized in order to define the understanding of Energiewende in this thesis (section 3.2). Third, the development of Germany's Energiewende is summarized in four phases from 1974 to present day (section 3.3). Fourth, policies and political statements are reviewed in order to identify their implicitly or explicitly voiced intention to foster innovation (section 3.4).

3.1 Fossil energy, environmental impacts and energy transitions

In all major economies today the system of the supply and consumption of energy is constructed around fossil fuels. Since the industrialization of agricultural societies in the 18^{th} and 19^{th} centuries the global energy consumption has risen tremendously and fossil sources have come to its supply at a share of roughly 80% today (cf. Figure 5). This means electricity is generated from coal, gas or oil, buildings are heated and cooled using oil and gas, and planes, vehicles and vessels run on combustion engines fuelled by oil derivatives.

Figure 5: Global final energy consumption 1800-2010 (schematic)



Source: Own schematic representation based on OECD/IEA (2015) and Worldwatch Institute (2015)

However, an energy system based on fossil sources comes at high environmental costs. Environmental consequences have developed simultaneously with fossil energy consumption. Environmental concerns started in the 1970s and 1980s when they revolved especially around local air and ground pollution. The emission of smoke, dust, carbon black and harmful and hazardous substances into the air and ground caused environmental problems such as smog, acid rain and ground water decontamination. Since the 1990s the focus of environmental concerns has increasingly shifted from a local to a global level to issues such as the depletion of the ozone layer in the atmosphere, the greenhouse effect, global warming and climate change.

Anthropogenic climate change due the greenhouse effect is the major environmental concern today. As a consequence of the combustion of fossil fuels certain gases such as carbon dioxide (CO_2), methane and ozone are released. A high concentration of these so-called greenhouse gases (GHG) in the atmosphere can lead to an increase in global temperatures. The greenhouse effect was first described in the 19th century, is systematically being investigated since the 1980s, and has been subject to fierce scientific and political debate. It is the scientific consensus today that this greenhouse effect as a consequence of human action exists and that causes the climate of the earth to change (Cook et al., 2013;

Liverman, 2007; Oreskes, 2004). While fossil fuels are not the only anthropogenic sources of GHG, deforestation and livestock play a role as well, they contribute the largest share by far. About ~75% of globally emitted GHG in 2010 originated from fossil fuels (IPCC, 2014, p. Working Group III). A higher global temperature has a profound impact on the climate of the earth in terms of melting glaciers and polar ice, rising sea levels, and frequent extreme weather conditions (Hoegh-Guldberg & Bruno, 2010; McCarty, 2001). These climatic changes in turn affect the livelihood of billions of people, exacerbate poverty, inequality and hunger especially in developing countries, and cause mass migration and geopolitical consequences (Reuveny, 2007). The economic repercussions of these changes are a significant reduction in global prosperity and welfare. The 2006 Stern Review, an assessment of climate change consequences by the British economist Nicolas Stern, found that 5% of the global gross domestic product (GDP) per year is at risk due to climate change (N. H. Stern, 2006).

The realization that local economic activities have global environmental consequences that will result in real economic costs has triggered international efforts to combat climate change. Environmental pollution was one of the main risk factors to the future development of the world and its inhabitants cited by the 1972 Club of Rome report *The Limits to Growth* (Meadows, Meadows, Randers, & Behrens, 1972), a report that is thought to have laid the foundation for the global discourse on sustainability that unfolded in subsequent decades (Mebratu, 1998). In 1988 the United Nations Environment Programme (UNEP) installed the Intergovernmental Panel on Climate Change (IPCC) to review the scientific evidence that climate change is taking place and is indeed anthropogenic. In 1992 the UN adopted the United Nations Framework Convention on Climate Change (UNFCCC) that has the prevention and mitigation of consequences of anthropogenic climate change as its core objective. Annual conferences of the signature parties (COP) are held to discuss international measures towards this objective. A milestone was the Kyoto Protocol, adopted in 1997 and effective in 2005, that prescribed target reductions for the GHG emissions of developed countries to be realized in the period 2008 to 2012. An extension of the Kyoto Protocol until 2020 was agreed in Doha in 2012 and a Kyoto succession treaty at the 2015 Paris COP (Bulkeley & Newell, 2015).

As a consequence of these binding international targets and national discourses on environmental and climate protection, countries around the globe are devising policy strategies to combat climate change. As energy is the prime anthropogenic cause of climate change, such climate policies typically combine energy policy with environmental policy (Giddens, 2009). This means, however, that in addition to the environmental aspect, recurrent issues of energy policy such as security of supply, safety, and affordability of energy are relevant in policy-making. Taking into account all of these factors, governments are devising visions, strategies and plans for their energy systems that often divert significantly from the status quo. Such *energy transitions*, i.e. shifts in the nature of how energy is supplied and utilized, are under way in many countries (Araújo, 2014).

Despite the environmental consequences, fossil fuels remain one of the options for energy supply. As the standard energy source globally they set the benchmark for costs, security of supply, and safety, that alternative energy sources need to compete against. Security of supply may become a concern for fossil fuels in the long run since they are exhaustible and will be depleted at some point. While this is a minor risk for coal as resources are abundant, an end to the cost-efficient supply of oil may be in sight in the medium to long term and the threat of it is already imminent in occasional oil price spikes (Hallock, Wu, Hall, & Jefferson, 2014). It is the same case for gas, however, cost reductions achieved in the production of unconventional gas in recent years, large untapped natural gas resources in the Middle East, and the ability to liquefy natural gas (LNG) and transport it at comparably low costs have moved this concern to the more distant future (Stevens, 2012). Also, there are risks to the supply of fossil fuels for geopolitical reasons. Much of the global reserves of oil, gas and coal are in politically instable countries from where supply may not always be secure, or desirable (Correlje & Van der Linde, 2006).

In addition to fossil fuels, energy from nuclear sources can constitute a pillar of an energy supply strategy. The technological progress achieved in the civilian use of nuclear energy for electricity generation in the 1960s and 1970s seemed to provide a viable alternative to fossil fuels for a long time because it was non-emitting and comparatively cheap (Weinberg, 1972). However, following the nuclear incidents in Chernobyl 1986 and Fukushima-Daichi 2011, as well as several smaller incidents and recurring failures, this has been called into question. First, uranium supply is by no means secure and is indeed subject to similar geopolitical risks as fossil fuels. Second, and more importantly, the safety risks for humans and the environment and with them the potential costs of nuclear energy are possibly infinite. Given that nuclear power plants only operate under government guarantees as insurance policies for nuclear power plants are not available on the private market, the true costs of nuclear energy may often be understated (Krewitt, 2007). However, nuclear strategy still varies massively across countries and nuclear energy has experienced a resurgence especially against the background of the environmental concerns regarding fossil energy sources (Nuttall, 2004).

Besides fossil and nuclear, governments have turned to a third source of energy supply, energy from renewables. Renewable energy sources (RES) are commonly defined as sources of energy supply that are inexhaustible in a human span of time and do not contribute to net GHG emissions. RES encompass solar irradiation, wind, water, biomass, and geothermal energy (Hennicke & Fischedick, 2007). While the physics behind RES and the basic technologies for tapping into their potential have been known since pre-industrial times, RES were only re-discovered as a solution for energy supply in the 1980s and today make up a tiny, but visible part of the global energy consumption mix of about 1% (cf. Figure 5). Most national governments now regard RES as a cornerstone of their energy policy in the light of climate change (Giddens, 2009).

In addition to changing the source of energy supply, climate change policies also involve several other measures to decrease the environmental burden of the energy system. There are many efforts to find safe and cost-efficient ways to decarbonizes fossil fuel, usually by capturing CO_2 emissions before they are released into the atmosphere and storing them underground (Viebahn et al., 2007). Furthermore, the reduction of absolute levels of energy consumption through increasing the energy efficiency of all products that use energy is also critical (Fischedick & Thomas, 2013; Hennicke & Fischedick, 2007). The challenge is to decouple energy consumption from economic growth, as they have been closely related since the beginning of industrialization (D. I. Stern, 1993).

Governments around the world diverge significantly in how they assess the different sources of energy and how they prioritize the individual objectives of climate policy. Consequently, energy transitions take on a variety of forms (Araújo, 2014).

While the United States (US) are at the forefront of developments in renewable energy, they also place great importance on the development of unconventional gas and oil produced with hydraulic fracturing and horizontal drilling. Given the high levels of energy consumption in commercial as well as private use, security of supply and affordability have long been at the heart of the energy policy discussion in the US. As domestic oil and gas reserves are depleting, the US has funded the exploration of these unconventional production methods. Production costs for unconventional gas and oil have tumbled throughout the 2000s, a development that enabled the US to cut oil imports and start exporting gas, shaking up both markets globally (Araújo, 2014). However, the US has been more hesitant than other developed countries to embrace clear targets and strategies against climate change. In fact, it refused to ratify the Kyoto Protocol, which almost caused the international climate effort to fail, and is yet to set long term targets for emission reductions. Nevertheless the US has made efforts to cut energy consumption and increase the deployment of renewables. RES support schemes are in place in all states (Laird & Stefes, 2009; Nemet, 2009; Taylor, 2008) and on a federal level, the Obama administration provided $ 70 million in funds for a modernization of the energy system.

The multilateral energy policy of the European Union (EU) is especially targeted at climate issues. The EU installed the worldwide largest cap-and-trade system for CO_2 emissions in 2005. The EU Emissions Trading System (EU ETS) defines the total amount of CO_2 that may be emitted by its members in a multi-year period, structures these emissions into emission permits and allows members to trade these permits so that members are incentivized to emit less than they are entitled to and profit from selling their permit instead[1]. The EU also sets targets for its member states regarding GHG emissions, energy consumption and the deployment of RES. Following the first set of such targets for 2020, another set of targets for 2030 was adopted in 2014 (European Commission, 2014a). Moreover, the EU regulations and directives have the reduction of energy consumption as their objective (European Commission, 2014b). However, albeit the EU it seems that the EU is an active and strong actor in energy policy, its domain of influence only extends over few of the areas that energy policy consists of. Overall energy policy remains a predominantly national policy domain even in EU member states and consequently there are large divergences between member states (Ide, in press).

In the United Kingdom (UK) the mitigation of climate change is the most important objective of energy policy and nuclear energy is considered a key pillar of this. While also promoting energy efficiency and renewables, nuclear energy remains a strategic cornerstone in order to reach the CO_2 emission reduction targets defined in 2007. Concerned with security of supply and affordability of energy, the UK is one of the few countries globally where the government has decided to support new nuclear power projects such as the Hinkley Point plant (The Economist, 2016a). Renewable energy was not on the political agenda until the

[1] A more detailed discussion of the EU ETS and its performance as well as cap-and-trade systems in general is beyond the scope of this thesis.

mid 1990s and never received the broad political support it got in other countries (Lipp, 2007).

In Denmark, enthusiasm for renewable energy, especially wind power, started already in the 1970s and the installation of wind power capacity surged in the 1990s due to political support and a well-functioning subsidy system. Consequently Danish firms are leading players in the global wind industry (J. I. Lewis & Wiser, 2007) and wind energy contributes ~40% to the domestic electricity mix (Energinet.dk, 2016). With domestic gas resources in the North Sea, fossil fuels still plays a role in the domestic energy mix today. In addition electricity is imported from European neighbors. However, the government has installed a long term energy strategy that previews a complete phase-out of fossil fuel sources until 2050 (Danish Government, 2011).

Germany has taken a somewhat unique path in comparison to its European and international peers. In Germany, opposition to nuclear energy as well as a focus on renewables is much more pronounced than in other countries. The dual objective to get to zero GHG emissions without the use of nuclear energy sources is the defining characteristic of the German *Energiewende* (Buchan, 2012). The following sections explain the German energy transition and the concomitant change process.

3.2 Definition of Energiewende for this thesis

Albeit being used extensively in recent academic literature and public discourse, the term *Energiewende* is not unambiguously defined. While generally speaking it has come to be understood as a change of Germany's energy system associated with a reduction of greenhouse gas (GHG) emissions and a phase-out of nuclear energy there are several underlying nuances of definition. First, many contributions frame Energiewende in terms of a political strategy focusing on targets set by the German government. These authors generally emphasize that Energiewende came into existence in 2011 following the Fukushima nuclear incident and is defined by the double objective to cut GHG emissions and nuclear energy (Buchan, 2012; The Economist, 2012, 2014a, 2014b). Second, Energiewende can be regarded as a process of political and socio-technical change. Many academic publications take this perspective on Energiewende and analyze the evolution of Germany's energy system since the 1970s. While political initiative and action is embedded in the accounts of systemic change, it is the system and the change itself that is studied and that defines Energiewende, rather than a deliberate political agenda.(Jacobsson & Lauber, 2006; Lauber & Mez, 2004;

Maubach, 2014; Strunz, 2014). Third, Energiewende can be viewed through its particular policies. Energiewende is often used synonymously for laws and regulations of German energy policy, especially the Renewable Energy Sources Act (*Erneuerbare Energien Gesetz, EEG*) (Böhringer et al., 2014; Frondel et al., 2010). Drawing on these works, the definition employed in this thesis is as follows:

Energiewende is the political course of action that drives a socio-technical transformation of the German energy system in an effort to make it greenhouse gas emissions and nuclear free.

This definition contains four key aspects which will now be explained in turn: political course of action; socio-technical transformation; German energy system; and greenhouse gas emissions and nuclear free. First, Energiewende is a *political course of action*. Clearly, the direction as well as the rate of change seen in the German energy system is to a large extent *politically-induced* (Jacobsson & Lauber, 2006; Sühlsen & Hisschemöller, 2014). In this way Energiewende policy is a combination of environmental policy, energy policy and innovation policy. There is a strong political drive and much of the change already envisaged e.g., the surge in electricity from renewable sources is hard to imagine without the respective deployment policies (Böhringer et al., 2014; Gawel et al., 2014). This stands in contrast to changes in other socio-technical systems, e.g., in information and communications, where technology evolved in the absence of a political agenda and regulation was only sought after major technological change had occurred (Ansari & Garud, 2009). The early political involvement in the change of the energy system may be due to the fact that energy has always been heavily regulated because of security of supply issues and the tendency to natural monopoly. Introducing any change to that system without corresponding changes to regulation seems impossible. Furthermore, the notion *course of action* also introduces a process element. Energiewende is not one policy or one set of policies at a single point in time. Rather, it is a dynamic mix of policy instruments that results from a distinct policy process. The elements of the policy mix cannot be fully understood without looking at the corresponding policy process (Jacobsson & Lauber, 2006; Rogge & Reichardt, 2013; Sühlsen & Hisschemöller, 2014).

Second, Energiewende is a *socio-technical transformation.* Transformation captures that the changes expected in the energy system are far-reaching and concern all system elements as well as the linkages between them. There is a common understanding that Energiewende – as the term suggests – constitutes a significant departure from the previous status quo in Germany's energy system and energy policy. Interpretation of the German term in English language range from "shift" (Strunz, 2014) over "transformation" (Jacobsson & Lauber, 2006) to "revolution" (Buchan, 2012; The Economist, 2014a). Increasingly though, "energy transition" seems to have become the term most frequently employed (Araújo, 2014; Gawel et al., 2014; Sühlsen & Hisschemöller, 2014; The Economist, 2012, 2014a, 2014b). The terms transition and transformation will – unless otherwise specified – be used synonymously in this thesis. In addition to this the term *socio-technical* transformation emphasizes that the change encompasses technological as well as social aspects and acknowledges the intertwinedness between technology and sociology. Within a system, changes to a technology, or physical elements, usually correspond with changes to the way that such technology is being used, or social elements (Geels, 2004).

Third, it is the *German energy system* which is being transformed. The *energy system* is the combination of actors (individuals, organizations, social groups), physical elements (technology, infrastructure) and non-physical elements (rules, norms, knowledge), which together determine the way energy is supplied and utilized. It is hence defined as a socio-technical system where material artifacts are erected by actors guided by formal and informal institutions in an effort to fulfill a certain societal function (Geels, 2004; Malerba, 2002). In Germany there is a strong tendency to only focus on electricity when talking about the energy system and deprioritizing energy used in form of fuels or heat. Indeed even Energiewende politics has a bias towards electricity (Rennings & Rexhäuser, 2014). However, in line with the public and academic discourse, this thesis will mainly stick to the association of energy with electricity and discuss other forms only when they are adjacent. The energy system is defined specifically for *Germany*. This limitation to a specific polity and geography makes sense when looking at energy systems since national energy systems are despite certain links rater separate from one another. While energy transitions towards sustainability are taking place in several countries, they differ significantly in terms of targets, priorities and speeds (Araújo, 2014). Even in the European Union energy supply remains a national affair despite ongoing efforts to integrate systems and markets and harmonize corresponding regulation. Competences regarding target energy mixes, electricity market design and regulatory oversight of power plants and infrastructure are firmly vested on the national level (Kitzing, Mitchell, & Morthorst, 2012).

Fourth, Energiewende takes place in an effort to make the energy system *GHG emissions and nuclear free*. There is no doubt that Energiewende aims at an energy system that is more sustainable, and in Germany sustainability in that respect is defined as an energy system with zero nuclear energy and close-to-zero GHG emissions. The term Energiewende only came into popular use after this dual objective was installed when, in the aftermath of the Fukushima incident, nuclear energy was unanimously repudiated (Buchan, 2012). This means Energiewende has a strong sense of direction, or normative attribute, to it. Not every change of the energy system and not every novelty will be associated with Energiewende, only change that promotes the dual objective is counted in that way.

This definition still leaves open a temporal specification of Energiewende as well as concrete elements and properties needed for empirical research. Both will be addressed later in this thesis in the development of the conceptual framework for empirical enquiry (cf. chapter 5).

3.3 A brief history of German Energiewende since 1974

Although the term *Energiewende* has only been used in popular discourse since 2011, Germany's energy transition looks back at a history of more than 40 years (Gawel et al., 2014; Jacobsson & Lauber, 2006; Lauber & Mez, 2004; Maubach, 2014; Strunz, 2014).

Four phases can be distinguished: First, a formative period between 1974 and 1990 where different sources of energy were contemplated, knowledge was created and actors promoting particular energy sources emerged. Second, a phase between 1986 and 1997 where nuclear energy was contested and renewable energy gained popularity as an alternative to both fossil fuels and nuclear, but stayed in a niche position. Third, a high-intensity phase with pushes and push-backs for energy policy between 1998 and 2010 where the climate change discussion intensified, bold political decisions were taken and reversed and changes to the energy system surfaced. Fourth, the current phase where Energiewende has become a mainstream term and the dual objective of zero GHG emissions and zero nuclear energy is widely accepted, but the implementation and path towards this objective is still emerging and critical voices remain strong.

3.3.1 1974–1990: Formation of scientific and societal vision

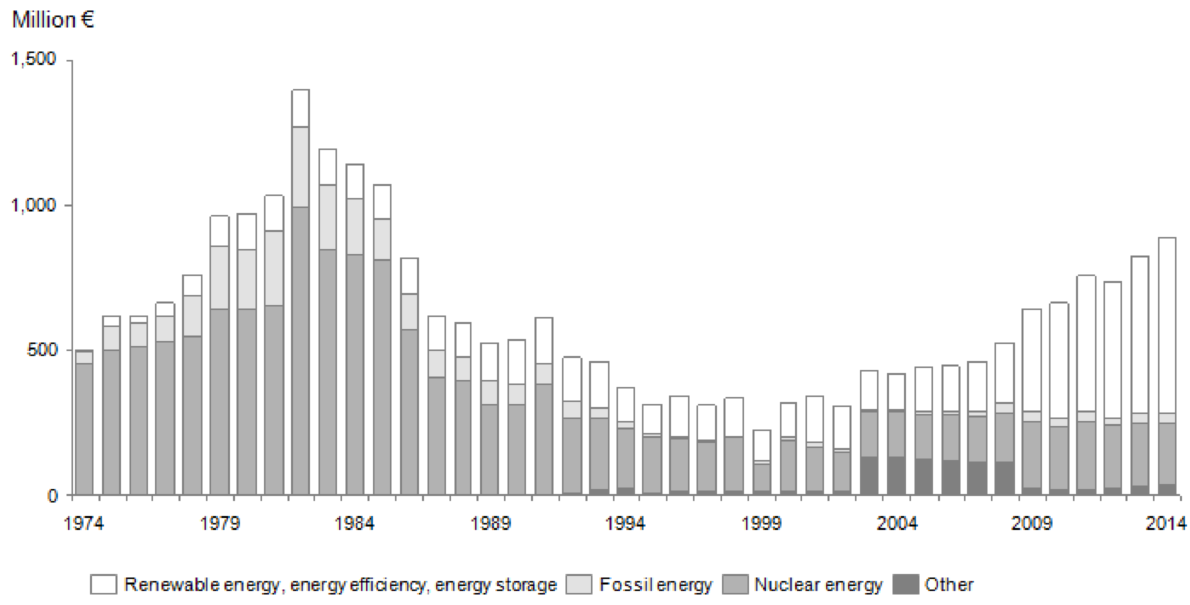
Between 1974 and 1990 the roots of the German energy transition developed from the need to seek alternative energy sources to oil and the vision of a clean energy future promoted by a rising ecological movement.

The starting date of the German energy transition is usually set in 1974 when in a response to the oil crisis the German government started to intensify its search for alternatives to oil to fulfill the energy demand of its growing economy. The Energy Research Program of the German federal government (*Energieforschungsprogramm*) devised in 1974 pooled publically funded research efforts in energy technologies. Given that security of supply was the focus of energy policy in the mid-1970s and that environmental concerns were still in their infancy, funds of the program were especially given to research in coal and nuclear (Lauber & Mez, 2004). In addition to research, also the deployment of coal as a fuel for electricity generation was subsidized. For example, a special tax levied on the electricity bills of retail consumers since 1975, the so-called Coal Penny (*Kohlepfennig*), was given to incumbent electricity suppliers in order to incentivize them to use hard coal mined in Germany to as fuel for their power plants (Jacobsson & Lauber, 2006).

At the same time, however, a vocal societal that opposed the construction of nuclear power plants movement emerged. Green grassroots groups sprung up in the 1970s locally in Germany wherever nuclear plants were supposed to be constructed and created nationwide political controversies around nuclear energy. In addition, there was also rising concern about the side-effects of the use of fossil fuels. While the greenhouse gas effect and climate change were not high on the agenda yet, local phenomena such as smog and acid rain spurred opposition to oil and coal. One of these groups, the anti-nuclear non-profit organization Öko-Institut was the first to coin the term *Energiewende* in a 1980 publication in which it mapped out its vision for a clean energy future without nuclear energy and fossil fuels (Bossel, Krause, & Müller-Reissmann, 1980).

Research into renewable energy technology and energy efficiency was introduced to the research program largely as a response to these societal demands. Many of the research projects were only directed at basic research, without the intention to develop technology to such an extent that it is suitable for a wider market launch. Large demonstrations such as the wind turbine GroWiAn were allegedly only funded to show that wind energy does not work. Overall throughout the 1970s and 1980s public funding for renewables was marginal compared to conventional energy technologies (cf. Figure 6). Nevertheless, universities, institutes and firms were able to carry out research, development and demonstration programs regarding the use of wind and solar energy and lay the foundations for renewable energy technology. Moreover, while the ruling political coalitions and business actors remained firmly united behind coal and nuclear, a niche of players in the renewables field began to form and develop into a powerful advocacy coalition for renewable energy in later years (Jacobsson & Lauber, 2006).

Figure 6: German federal government energy research expenditures 1974-2014



Source: 1974-1990 data from Diekmann & Horn (2007), 1991-2014 data from BMWi

3.3.2 1986–1997: Chernobyl, political initiatives and societal mainstreaming

Between 1986 and 1997 the Chernobyl nuclear disaster and the emerging discourse on climate change triggered first political initiatives to support renewable energy beyond research funding. The nuclear meltdown in Chernobyl in 1986 that was accompanied by a radioactive cloud that contaminated the soil in parts of central Europe exacerbated the German skepticism regarding nuclear power. Public opinion, which had been tied throughout most of the 1970s and 1980s, turned against nuclear (Lauber & Mez, 2004). The social democratic party (SPD) was the first large German party that vowed to phase-out nuclear power. In addition, a report published in 1986 on impending climatic change due to greenhouse gas emissions and its dramatic consequences put the topic on the political agenda and increased the sense of urgency to push for a market introduction of renewable energy. While the Christian Democratic (CDU) government remained reluctant, parliamentary motions led to several market formation programs and eventually the adoption of the Feed-in Law (*Stromeinspeisegesetz, StrEG*), which required electricity suppliers to connect renewables capacity to the grid and buy electricity generated from RES at a rate of 90% of the electricity retail price for wind and solar. This provided a great investment incentive for wind energy, with installations increasing significantly in subsequent years and dynamic industry developing (J. I. Lewis & Wiser, 2007). For solar power, however, the feed-in-tariff was still too low to promote investment since solar technology remained significantly more expensive than wind (Lauber & Mez, 2004). Installation of solar technology remained confined to special subsidized programs such as the 1989 1,000 Roofs Program, but faded again afterwards. Throughout the 1990s the most effective support for solar energy came from initiatives on the level of German states (*Länder*) and municipalities who ran market introduction programs through generous feed-in laws and subsidizing the installation of solar cells on public buildings. Although they remained limited in scale, these initiatives triggered the development of an infant solar industry with start-ups firms as well as some energy technology incumbents. On all political levels and across all parties the support for renewable energy increased steadily throughout the 1990s. The *Kohlepfenning* hard coal subsidy was abolished in 1995 after a Constitutional Court (*Bundesverfassungsgericht*) ruling that condemned it as unlawful cross-subsidization of an industry not of general public interest (Jacobsson & Lauber, 2006).

3.3.3 1998–2010: Political push and push-backs

Between 1998 and 2010 significant changes took place with the liberalization of the electricity markets, the introduction of a powerful feed-in tariff through the German Renewable Energy Sources Act (*Erneuerbare Energien Gesetz, EEG*), the first nuclear phase-out decision, and the subsequent fierce political debate about benefits, costs and pace of the German energy transition.

The German energy industry had until 1998 mainly been regulated by the 1935 Energy Industry Act (*Energiewirtschaftsgesetz, EnWG*) that put it under public oversight, granted regional monopolies and exempted firms from the competition laws valid in other industries. The EnWG was overhauled in 1997 backed by the EU initiative to liberalize electricity markets across the European Union. The amended EnWG that entered force in

April 1998 introduced competition by abolishing monopolies, permitting third parties access to the electricity network and granting consumers free choice of their electricity supplier. After some hesitation large electricity incumbents generally welcomed the reform as it enabled them to pursue expansionist strategies (Bontrup & Marquardt, 2015; Lauber & Mez, 2004). Liberalization was taken another step further in 2005 when in another amendment to the EnWG large electricity suppliers were mandated to carve out transmission grid networks, i.e. those electricity grids that transport electricity over large distances through high voltage lines, from their firms and organized as independent entities. This "unbundling" of the electricity supply value chain was supposed to limit the impact of large firms by taking key infrastructure assets away from them. Mirroring the regional structures of their previous parent companies, four transmission system operators (TSOs) emerged from this process. Distribution grid networks, however, i.e. low voltage lines that distribute electricity from transmission lines to consumers, were not part of the reform and remained in the hands of their previous owners.

In 1998, the Social Democrats (SPD) and the Green Party were elected to replace the Christian Democratic (CDU) and Liberal (FDP) federal government. The new red-green coalition made energy policy a priority for their first term in office. Immediately after being elected they introduced a 1,000,000 Roofs Program for the installation of solar cells. Furthermore, they fundamentally reformed the Feed-In Law in an effort to remove all remaining barriers to the widespread adoption of renewable energy. The Renewable Energy Sources Act (*Erneuerbare Energien Gesetz, EEG*) passed in 2000 provided a comprehensive and far-reaching initiative to promote the installation of RES generation capacity. In contrast to the StrEG feed-in tariff that had been linked to the electricity price and was therefore subject to fluctuations, the EEG guaranteed investors fixed return rates for RES electricity fed into the grid. Grid operators were mandated to grant RES electricity preferential grid access and take on all RES electricity generated. Moreover, feed-in rates differed by RES technology depending on the cost difference to electricity from conventional sources. This was especially important for the promotion of solar energy. Whereas the feed-in rate for wind energy turned out to be only about 10% higher as the average rates received under the StrEG, solar energy benefited from a more than five-fold increase in return. Also, rates were fixed for a 20 year period providing investors with a maximum amount of security (Bürer & Wüstenhagen, 2009). To reflect anticipated reductions in technology costs, the fixed rates were set to decline for new installations every year. In addition, a new financing mechanism, the EEG surcharge (*EEG Umlage*), was introduced in which the costs incurred for the feed-in-tariffs were redistributed as an additional levy on the electricity bills of residential, commercial and industrial electricity consumers in all of Germany. The *EEG Umlage* follows the polluter pays principle, which holds that who consumes more, pays more. This constituted a departure from the financing mechanism of the StrEG where feed-in-tariffs had been financed by electricity consumers locally, which imposed higher burdens on consumers in areas with a high RES production volume. Targets to increase the share of RES-E in the German electricity mix to 12.5% in 2010, 20% in 2020 and 50% in 2050 were set (Lauber & Mez, 2004).

Based on the longstanding opposition to nuclear power that united the two coalition partners they made putting an end to it a priority in their energy policy that they pursued in parallel to promoting RES. Negotiations between the federal government and the four national electricity suppliers as owners of the German nuclear power plants reached an agreement in 2000, that was signed in 2001. The core provision of the consensus, which entered into legal force in the 2002 amendment to the Nuclear Energy Act (*Atomgesetz*), was the agreement to fixed remaining nuclear electricity production volumes (*Reststrommengen)* for each of the four electricity suppliers and an expiration of the operating licenses of nuclear power plants as soon as these electricity volumes had been produced, which was expected to be the case in 2022. There was hence no fixed date, but fixed production volumes that set the end of nuclear energy.

In addition, the coalition government sought a greening of the tax system, that is the abolishment of subsidies for environmentally-harmful practices and the installation of taxes to reflect the external costs of energy consumption in the price paid for energy. As part of this effort, a tax on electricity consumption was introduced in 1999 and taxes on fuels from mineral oils, that is gasoline, diesel and natural gas, raised step-wise until 2003 (Lauber & Mez, 2004). While the official name of these efforts was First Step Towards An Ecological Tax Reform Act (*Gesetz zum Einstieg in die ökologische Steuerreform*), the reforms quickly adopted the name Eco-Tax with a strong negative connotation in popular discourse. In other political initiatives, the deployment of combined heat and power (CHP) technology for electricity and heat generation was strengthened in the 2002 Combined Heat and Power Act (*Kraft-Wärme-Kopplungsgesetz, KWKG*) and the reduction of energy consumption and increase in energy efficiency was supported in the 2002 Energy Savings Decree

(*Energieeinsparverordnung, EnEV*), which sets standards, limits and reporting guidelines for the energy use of new and renovated commercial and residential buildings.

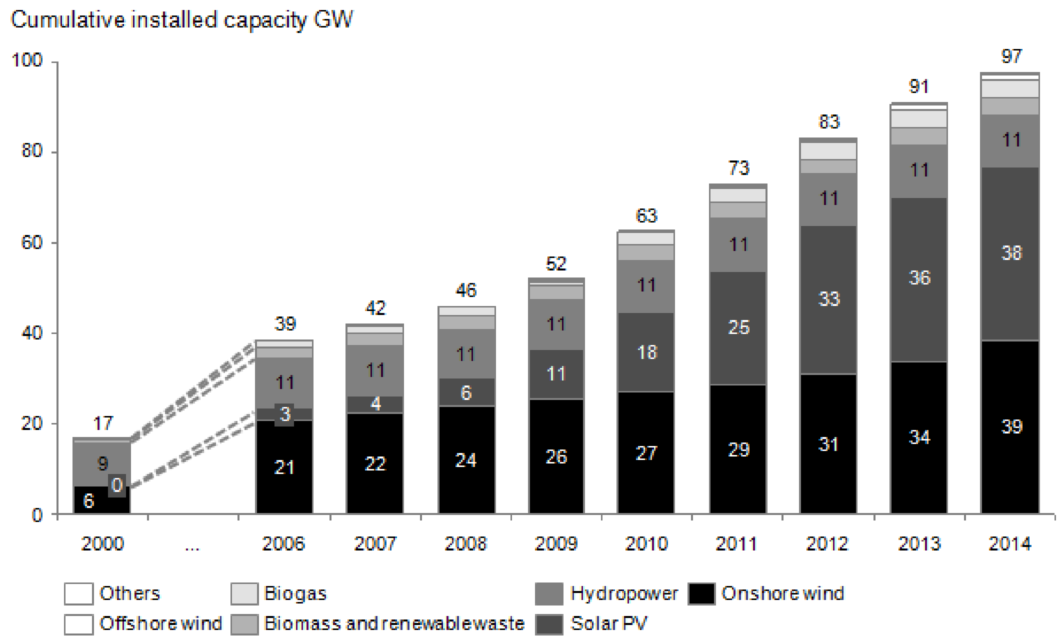
The strong push towards a different energy system initiated by the Red-Green coalition ensued a "battle" (Jacobsson & Lauber, 2006, p. 16) between political parties, political institutions, business actors and civil society that enfolded throughout the 2000s.The Federation of German Industry (*Bund der Deutschen Industrie, BDI*) as well as the German Association of Energy and Water Industries (*Bund der Elektrizitäts- und Wasserwirtschaft, BDEW*) repeatedly criticized the EEG and the ecological taxes for raising energy prices and hence putting an unfair burden on society and damaging the competitiveness of the Germany economy. In addition divergences occurred between federal ministries as well as between and within political parties. On the other hand, the emerging renewables industry became a political influence in its own right (Sühlsen & Hisschemöller, 2014).

The new Grand Coalition government that replaced the Red-Green coalition in 2005 was, tainted by the conservative influence of the CDU and the worries regarding employment in extractive and manufacturing industries of the SPD, much less enthusiastic of the energy transition than its predecessor. However, with the trajectory already started, one party of the old coalition also being part of the new one, and international and EU pressure to support initiatives for mitigating climate change mounting, previous legislations were not revoked. In 2007, the government outlined its energy and climate policy in the so-called Meseberg Decisions (*Meseberger Beschlüsse*) that described an Integrated Energy and Climate Program (*Integriertes Energie- und Klimaprogramm, IEKP*). The IEKP set out objectives and measures for 29 topics encompassing i.a. renewable energy, clean conventional energy, smart energy and energy management, biofuels, and transport.

Several policy initiatives followed this program. After changes to the EEG in 2003 and 2004 that had already lowered tariff rates, it was amended again in 2008/2009. A 30% target share for RES-E in the electricity mix in 2020 was adopted, an automatic reduction of tariff rates depending on growth in the deployment of solar energy introduced, and regulatory details were adjusted. In addition, the Renewable Energy Heating Act (*Erneuerbare Energien Wärme Gesetz, EEWärmeG*) was passed setting the target to achieve 14% renewable share in the provision of heat energy by 2020, mandating certain shares of energy from RES for heating and cooling in new buildings, and installing a fund (*Marktanreizprogramm, MAP*) to subsidize the modernization of buildings involving RES. A phase-out of subsidized hard coal mining was finally decided in 2007.

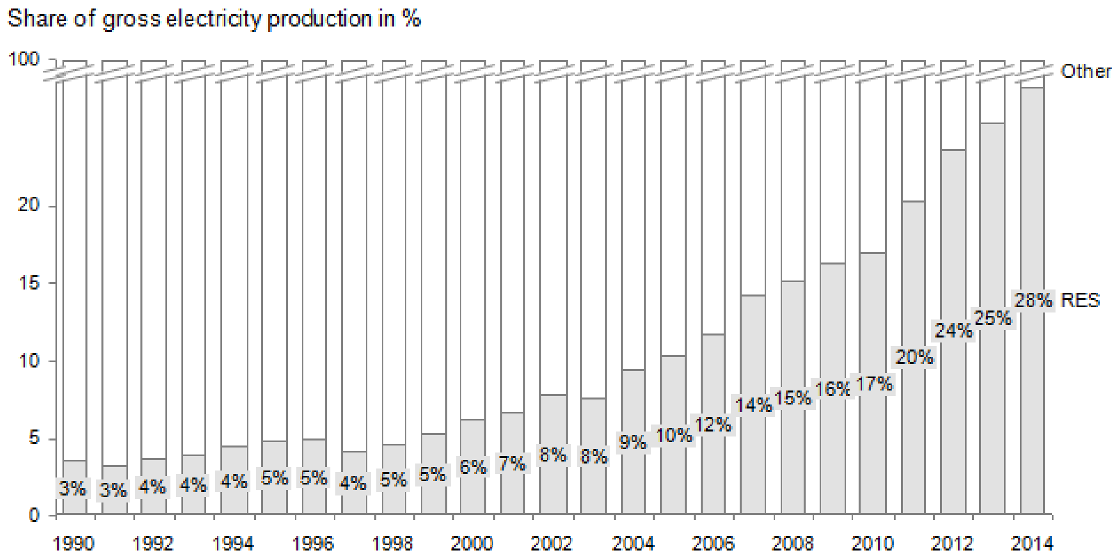
Meanwhile, the importance of renewable energy in Germany grew enormously. RES-E capacity installed almost quadrupled between 2000 and 2010 from ~17 GW to about ~63 GW. Due to the technology-differentiated feed-in tariffs of the EEG, solar energy saw an especially drastic increase from less than 1 GW installed capacity in 2000 to ~11 GW installed capacity in 2009 (cf. Figure 7). In 2010 RES-E contributed ~17% to the German electricity mix, almost a tripling from the ~6% in 2000 (cf. Figure 8). Concomitant to this development, a shift in the geographical distribution of generation capacity in Germany occurred. Generation capacity moved from the German South to the North, given the wind resources on the shores of the North Sea and Baltic Sea. In addition, decentralization took place as generation capacity shifted from a few large power plants with high energy-density in their output to many, small locations producing relatively small amounts of electricity. The rise in the RES-E share also brought more volatility into the electricity supply. As wind and solar irradiation is not constant, the previously steady electricity production became subject to fluctuations of supply depending on weather conditions.

Figure 7: German cumulative installed RES-E capacity 2000 - 2014



Source: Own graphic with data from IRENA (2015)

Figure 8: Share of RES-E in the German electricity mix 1990 - 2014



Source: Own graphic with data from BMWi (2015c)

As a consequence of these developments the electricity grid network came increasingly under pressure, forcing politicians to make plans for its expansion and upgrade. An EnWG amendment in 2006 obliged the TSOs to ensure grid connection for all offshore wind power capacity by the time that construction of the offshore wind power plant was completed. In 2009, the Energy Grid Expansion Act *(Energieleitungsausbaugesetz, EnLAG)* permitted a number of urgent transmission grid expansion projects and laid down mechanisms to govern their speedy implementation.

In 2010 the Conservative-Liberal Coalition that had come into power in the previous year outlined its vision for a clean, secure and affordable future energy system in its Energy Concept (*Energiekonzept*). Given that none of the coalition parties was responsible for the nuclear phase-out decision in 2000 and holding that nuclear energy as a non-GHG-emitting fuel constituted an important interim source of energy to ease the transition into a renewable future, a key element of the Energy Concept was the pronounced deceleration of the nuclear-phase out. Nuclear energy was given a "bridging role" until renewable energy can by itself, reliably satisfy the electricity demand. The permissible electricity generation volumes for nuclear power plants (*Reststrommengen*) were increased in such a way that the expected the operating times of nuclear power plants were extended by 12 years on average, postponing the phase-out to 2036 from previously 2022 (Buchan, 2012). In return for the extensions to the life span and to appease critical voices from the political opposition, the German *Länder*, and civil society, a Nuclear Fuel Tax (*Kernbrennstoffsteuer*) was installed, the returns of which were supposed to be used for future nuclear decommissioning. In addition, the operators of nuclear power plants agreed to contribute payments to an Energy and Climate Fund (*Energie- und Klimafonds, EKFG*) for the promotion of research and development for a new energy system.

The Energy Concept also stipulates ambitious long term objectives and a roadmap for the reduction of GHG emissions, the increase of RES deployment and the increase of energy efficiency. Targets go beyond those of other European states and beyond what is required under EU or international obligations (Buchan, 2012, p. 2). Regarding GHG emissions, the target is a reduction of GHG emissions by 40% by 2020, 55% by 2030, 70% by 2040 and 80-95% by 2050, compared to 1990 levels. Regarding energy from RES, the targets are an 18% share of gross final energy consumption by 2020, 30% by 2030, 45% by 2040, and 60% by 2050. Regarding electricity from RES, the targets are a 35% share of gross electricity consumption by 2020, 50% by 2030, 65% by 2040, and 80% by 2050. Regarding energy efficiency, the targets are a 20% reduction of primary energy consumption by 2020 and a 50% reduction by 2050, compared to 2008 levels. Gross electricity consumption is supposed to decrease by 10% by 2020 and 50% by 2050, compared to 2008 levels. The target for final energy consumption in transport is a reduction of 10% by 2020 and 40% by 2050. In addition, final energy productivity is supposed to grow by 2.1% per year and the modernization rate of the building stock is supposed to increase to 2%, with no date for target achievement set. An overview of all quantitative targets of the Energy Concept can be found in Table 3 below.

Table 3: Targets of the 2010 Energy Concept

Area	Indicator	N. d.	2020	2030	2040	2050
GHG emissions	Reduction in GHG emissions compared to 1990 in %		-40 %	-55 %	-70 %	-80 - -95 %
Renewable Energy	Share of RES in gross final energy consumption in %		18%	30%	45%	60%
	Share of RES in gross electricity consumption in %		35%	50%	65%	80%
Energy Efficiency	Primary energy consumption compared to 2008 in %		-20%			-50%
	Final energy productivity growth per year in %	2.1%				
	Gross electricity consumption compared to 2008 in %		-10%			-25%
	Modernization rate building stock per year in %	2%				
	Final energy consumption in transport compared with 2005 in %		-10%			-40%

Source: Bundesregierung (2010)

3.3.4 2011–present: Accelerated Energiewende

Six months after the publication of the Energy Concept, in March 2011, a series of nuclear accidents and meltdowns occurred in the Fukushima Daiichi nuclear power plant in Japan as a result of damages caused by an earthquake and a tsunami. In Germany, the event stirred up memories of the Chernobyl nuclear accident in 1986 and reignited opposition against nuclear power. Only days after the event the federal government ordered a moratorium for nuclear energy (*Atommoratorium*) which meant that during a three months period a safety check for all German nuclear power plants was carried out, and eight particularly old and vulnerable plants were shut down. In the same document the government first used the term *Energiewende* to refer to the transition towards an RES-based energy system, a development it vowed to accelerate (Bundesregierung, 2011a). An ethics commission was installed to make recommendations for the future of nuclear energy in Germany. In its conclusions, published in May 2011, the commission recommended the phase-out of nuclear energy within a decade (Töpfer et al., 2011). In concomitant changes to the Nuclear Energy Act in June 2011, the extension of the life span of nuclear power plants was officially revoked. The eight plants shut down in March were permanently decommissioned and the working life of the remaining plants limited to 2022, irrespective of the remaining electricity production volumes granted previously. This decision put an end to four decades of fierce political and societal debates about nuclear energy in Germany (Kohler, 2011). An energy system based on renewable energy and without nuclear became the consensus and no societal group fundamentally challenged it anymore (Maubach, 2014, p. 24).

Critically, despite the u-turn regarding nuclear power, the federal government maintained the ambitious climate policy targets of the Energy Concept. Outlining its strategy regarding energy policy in June 2011, the federal government pledged that renewable energy will be the core pillar of the German energy system and that RES deployment targets as well as the targets pertaining to the reductions of GHG emissions and energy consumption remain valid (Bundesregierung, 2011b). While conceding that fundamental restructuring of the energy system is still required, the federal government promised to remove all remaining barriers, especially regarding grid expansion, and implement Energiewende in a cost-efficient and market-friendly manner. It admitted, however, that the plan constituted a "squaring of the circle" in energy economics (Bundesregierung, 2011b). Buchan (2012) argues that maintaining the targets of the Energy Concept constituted the true noteworthy aspect of the German energy policy decisions after Fukushima. It was no return to the energy policy status quo of the 2000s, because the targets of the Energy Concept and the ambition to achieve them created a radically new situation (2012, p. 3). Strunz (2014) seconds this analysis and holds that the political decisions in the aftermath of the Fukushima nuclear accident sealed the shift from a fossil-nuclear to an RES-based German energy system (Strunz, 2014, p. 157). Many observers, however, expressed concerns regarding their feasibility. The Economist positively notes the ambition of Germany's Energiewende and its potential to be a lighthouse for energy transition in industrial economies, but also calls it a Energiewende "risky" endeavor that is "more a marketing slogan than a coherent policy" and comprises a "set of timetables for different goals" rather than a consistent implementation plan (The Economist, 2014a, 2014b).

Clearly, as the end of nuclear energy was moved forward, issues connected to the change of the energy system became more urgent. One aspect was the expansion of the electricity grids, especially the transmission system. In 2011, the Grid Expansion Acceleration Act (*Netzausbaubeschleunigungsgesetz, NABEG*) was passed to facilitate the planning and approval of grid expansion projects. In 2013, the Grid Development Plan (*Netzentwicklungsplan, NEP*) built on the 2009 EnLAG to list and prioritize those grid expansion projects essential to maintain grid stability. The implementation of these projects was later mandated by the Federal Requirements Plan Act (*Bundesbedarfsplangesetz 2013, 2015*). In addition, also energy consumption and energy efficiency were targeted again. In 2014, the National Action Plan on Energy Efficiency (*Nationaler Aktionsplan Energieeffizienz, NAPE*) stipulated energy efficiency in buildings, energy efficiency business models and responsibility for energy efficiency as three action fields in the area. Fifteen measures targeting information provision, financial support and championing were designed to implement these (BMWi, 2016a).

The EEG was revised again in 2012, 2014 and 2016/2017. The 2012 amendment contained significant changes to the rate of the feed-in tariffs, especially a tariff reduction for solar energy as the market had overheated, and paved the way for a replacement of the feed-in-tariff system with the introduction of direct marketing (*Direktvermarktung*) for RES-E. Under the direct marketing mechanism, owners of RES-E generation capacity could opt to sell their electricity on the wholesale market instead of receiving a fixed feed-in tariff. They were incentivized to do so by a market premium (*Marktprämie*), a payment that compensates for the difference between the average return realized for selling electricity on wholesale markets and the applicable feed-in tariff. The tariff rate is hence not paid in full to producers of RES-E, but just as a difference to electricity wholesale prices. In addition, a management premium (*Managementprämie*) compensates for the transaction costs incurred through direct marketing and a flexibility premium (*Flexibilitätsprämie*), only applicable to owners of biogas power plants compensates them for the flexibility of generation they offer. The so-called Green Power Privilege (*Grünstromprivileg),* an exemption from the EEG financing mechanism (*EEG Umlage*) granted to electricity suppliers with at least 50% of their electricity from renewables, was also introduced in 2012, but abolished again in a subsequent amendment.

The 2014 and 2016/2017 EEG amendments fundamentally changed the course of RES-E support through an increasing emphasis on market-based RES-E promotion. The 2014 EEG amendment defined deployment corridors (*Ausbaukorridor*) for each RES-E technology that specify the extent to which RES-E capacity will be added in the future. It also moved away from the direct pay-out of feed-in tariffs by making direct marketing mandatory for new installations. Following this trajectory, the 2016/2017 EEG amendment that entered into force in January 2017 introduced another fundamental change. It abolished the fixed regulator-set feed-in tariffs for installations greater than 750 KW altogether, and replaced it with a system of tenders and auctions. For each new installation the tariff rate as upper limit for the market premium is not set by regulators in advance, but determined through auctions. Prospective investors of RES-E capacity participate in an auction by submitting single sealed bids for the market premium that they require to install a certain amount of RES-E capacity at a certain site. Bids are accepted from low to high until capacity has been added in line with the plans of the deployment corridors. This constitutes a far-reaching and much debated change to RES-E promotion in Germany as it leaves the subsidy rate up to market mechanisms and thus departs from the system of government-set feed-in tariffs that had constituted the cornerstone of RES-E promotion since the StrEG (BEE e.V., 2016b; Fürstenwerth, Praetorius, & Redl, 2014; Luhmann, Fischedick, & Schindele, 2014; WWF, 2016).

Germany's ambition for an energy transition based on renewable energy, with zero GHG emissions and zero nuclear energy hence remains unchanged. Currently the Energiewende legislative framework on the national level is made up of the strategy contained in the Energy Concept, more than 20 legal acts in the areas of energy generation, consumption, transmission and distribution, and storage and more than 30 ordinances regulating the implementation of these acts (BMWi, 2014d, 2016c). In addition to the previously mentioned topics, a few issues feature in the recent political debate. A reform to the electricity market design has been investigated in policy proposals and consultation procedures since 2014 and was finally decided in summer 2016. The key question was if the wholesale electricity price should also compensate for the provision of capacity instead of "energy only" in order to incentivize adequate investments in generation capacity (BMWi, 2014b). In addition, a harmonization of European energy policy is always on the agenda, specifically also finding a solution for the Europe-wide promotion of RES. Also, taking steps towards a closer integration of the three energy forms electricity, heating and transport (*Sektorkopplung*) is in focus.

Recently, there have been serious doubts that the 2020 targets of the Energy Concept will be met. The deployment of renewable energy in electricity seems to be on track, however, all other areas are lagging beyond what is required to meet the targets. The shares of RES in heating and transport are virtually stagnating. Primary energy consumption is falling, but a doubling of the pace of recent years would be needed to achieve the 2020 target of a 20% reduction. The reduction of gross electricity consumption may be on track, however, it is unclear whether it will continue at the current rate. In transport, final energy consumption seems to be rising. Final energy productivity growth would need to double until 2020 in order to, on average, reach the annual target rate since 1990. To achieve the 2020 GHG emission reduction targets, the annual rate of reductions would even need to triple from the current rate. Overall, there is significant risk to target achievement (Löschel, Erdmann, Staiß, & Ziesing, 2015). And even beyond the immediate Energy Concept, there is also fear that the broader targets of a secure, affordable and environmentally-friendly energy system may be missed (The Economist, 2016b). Apparently, the energy system is not changing, or not changing fast enough.

3.4 Innovation effect intended by politics

Throughout the course of the German energy transition policy makers have made statements to the importance of innovation for the transition process. Besides the immediate targets of the Energiewende strategy and the individual policies, Energiewende is supposed to foster innovation. Implicitly or explicitly, innovation is an objective of several of the policies reviewed in the previous section. However, the innovation target remains very vague. It has not been defined in clear terms, neither qualitatively nor quantitatively.

On the strategic level, the 2010 Energy Concept is very vocal on innovation as an objective of Energiewende as well as a means to achieve the energy transition anticipated. It holds that, "to make the transition to the age of renewable energy, it will be necessary to thoroughly modernize the energy sector. Innovation is key to the structural changes that are necessary to achieve a sustainable energy supply. Aside from basic research this primarily means using applied science funding to pave the way for both renewable energies and efficient technologies to achieve market penetration." (Bundesregierung, 2010, p. 26). Innovation is supposed to be achieved through market-oriented policies that ensure competition between firms in the energy industry and other relevant sectors, as well as specific funding for research and development (BMWi, 2012a; Bundesregierung, 2010). According to the Energy Concept, innovation policy is hence an integral part of Energiewende (Bundesregierung, 2010, p. 7). Going forward beyond 2011, innovation is especially sought in the following five areas: renewable energy, energy efficiency, energy storage and grid technology, integration of RES into the energy supply system, integration of different energy technologies (Bundesregierung, 2010, p. 33).

Moreover, policy instruments that directly support research & development state innovation as a target. The Sixth Energy Research Programme of the federal government (*Energieforschungsprogramm*) holds that new ideas and technological progress are instrumental to use natural resources to their fullest potential. "Innovation and new technologies will pave the way for a new age of renewable energy " (BMWi, 2011, p. 3). The funds of the Energy and Climate Fund (*Energie- und Klimafonds, EKFG*) are specifically directed at supporting research and innovation in energy technologies.

In other policy instruments innovation is a secondary objective that is supposed to come from a dynamic, i.e. indirect, effect of that policy instrument. Although not mentioning the term innovation in the law as such, the EEG is clearly geared towards it. By incentivizing the deployment of RES-E technology it aims to contribute to the widespread adoption and diffusion of such technology (Böhringer et al., 2014). The increased production volumes of such diffusion will result in economies of scale and learning that will then reduce the costs of producing and acquiring such RES technology. The same holds for the EEWärmeG with respect to RES technology in heating and cooling and the KWKG with respect to combined heat and power (Hennicke & Fischedick, 2007).

In addition to innovation in the sense of technological progress, the role of non-technological innovation is also explicitly recognized. For example, the development of business models with respect to energy efficiency is one objective of the National Action Plan for Energy Efficiency (*NAPE*) (BMWi, 2014e, p. 29).

As to why innovation is important, three objectives are recurrently mentioned (BMWi, 2011, 2012a, 2014f; Bundesregierung, 2010).

- First, innovation *lowers the costs* of implementing the energy transition by increasing the performance or reducing the costs to provide technological and non-technological solutions.
- Second, innovation *develops solutions* for current obstacles to the energy transition, which need to be overcome in order to be able to sustain an energy system with 100% renewable energy.
- Third, innovation *secures competitiveness* for German companies either in terms of global market shares in the energy and environmental sectors, or through low costs of energy as a production factor, especially in energy intensive industries.

Although innovation is hence clearly critical to making the German energy transition work and policy makers formulate innovation as an objective of the Energiewende strategy as well as its policy instruments, there are no concrete targets defined. This makes it hard to measure the success of Energiewende policies with respect to innovation (Löschel et al., 2014c). The following chapter will review the current state of research and evaluations of an innovation effect of Energiewende policies.

4 Current state of research regarding an innovation effect

This chapter reviews evaluations of the innovation effect of Energiewende in an effort summarize the current state of knowledge regarding the innovation effect and point out research gaps and controversies.

There is a controversial debate with mixed empirical evidence regarding the effect of Energiewende on corporate innovation. This is not a surprise; with a construct as complex as Energiewende that has evolved over time and has the potential to affect every sector of the German economy, the assessment of the innovation effect is a challenge to say the least.

This chapter is organized as follows. First, findings regarding innovation from the official monitoring Energiewende monitoring process installed by the federal government are studied (section 4.1). Second, independent academic research on an innovation effect of the energy transition is reviewed (section 4.2), distinguishing between innovation related to the use of renewable energy sources for electricity generation (RES-E) (section 4.2.1) and innovation beyond RES-E (4.2.2). Building on these reviews, three research gaps as well as three controversies prevailing in the current literature are pointed out (section 4.3).

4.1 Official Energiewende monitoring process

The German federal government assesses innovation as one criterion in the "Energy of the future" monitoring process on the progress of Energiewende. The monitoring process was set up in fall 2011 to review the progress towards achieving the objectives and targets set by the 2010 Energy Concept and the 2011 nuclear phase-out decisions (BMWi, 2012b). Monitoring reports are compiled by the Federal Ministry for the Economy and Energy (BMWi) annually and reviewed by an independent commission of academic experts. The report and the expert statement are published in the last quarter of each year reporting on developments in the preceding year. Every three years the monitoring report is published as part of a larger, more comprehensive progress report that covers past developments as well as future perspectives. Table 4 provides an overview of the reports published as part of the Energiewende monitoring process at the time of writing.

Table 4: Reports of the Energiewende monitoring process

Reporting year	Monitoring report	Published
2011	First monitoring report "Energy of the future" and expert commission statement	Dec. 2012
2012	Second monitoring report "Energy of the future" and expert commission statement	Apr. 2014
2013	First progress report "Energiewende" incl. third monitoring report and expert commission statement	Dec. 2014
2014	Fourth monitoring report "Energy of the future" and expert commission statement	Nov. 2015

Source: Adapted from BMWi (2016b)

The BMWi's monitoring reports have dedicated chapters or sections on innovation where they consider aspects in relation to federal government funding for research and development (R&D), federal grant and loan programs for the deployment of new technology, patent applications, and industry and export initiatives. Although part of the larger innovation process in the Schumpeterian sense (cf. section 2.1.1,

Figure 2), diffusion is not explicitly addressed in the innovation section, but implicitly included in the sections reporting on renewable energy, energy-efficiency, heating, transport, power plants, and electricity grid infrastructure.

The various monitoring reports suggest that a diffusion of innovations regarding renewable energy, energy efficiency, and the grid infrastructure has taken place as a result of Energiewende policies. Table 5 provides an overview of the most important figures from the 2014 monitoring report that indicate a diffusion of socio-technical novelties relevant to Energiewende in renewable energy, energy efficiency and grid infrastructure.

For renewable energy, the report notes the rise of renewable energy sources (RES) as a share of gross final energy consumption to 13.5% in 2014, a positive development. Looking at the different formsof energy individually, the share of RES in electricity consumption is 27.4%, on course to meet the 2020 target of 35%. Progress is also reported regarding the rising shares of RES in heating (12%) and transport (5.6%), both areas, which have tended to lag behind electricity (BMWi, 2015b, p. 13). These suggest that the deployment of RES on the energy supply side is picking up, a development that is attributed to the Renewable Energy Sources Act (EEG) for electricity, and the Renewable Energy Sources Heating Act (EEWärmeG), investment subsidies, and subsidized loan programs and other incentive programs to the deployment of RES technology for heating (BMWi, 2014c, p. 84).

Regarding energy efficiency, the report states that in 2014 total primary energy consumption has declined to its lowest level since 1990 and stands at -8.7% compared to 2008 level. The 2020 target is -20% compared to 2008. This figure alone does not indicate innovation as the reduction could be due to less economic activity. However, the concurrent rise in final energy productivity by 1.6% annually from 2008 to 2014 suggests that at least part of the decrease in consumption is due to more efficient ways of energy usage, i.e. innovation (BMWi, 2015b, p. 23). The report attributes this to the positive effect of the National Action Plan on Energy Efficiency (Nationaler Aktionsplan Energieeffizienz, NAPE) (BMWi, 2015b, p. 24, 26f). Differences surface, however, when looking at the individual forms of energy consumption. The increase in the productivity of electricity is larger than the overall increase in the productivity of energy, suggesting that electricity is leading the pack. The report suggests that this is a positive effect of the European Union directives on Ecodesign and Energy Labelling[1] (BMWi, 2015b, p. 28). The heat consumption as well as the primary energy consumption of buildings has decreased in 2014 compared to 2008, -12.4% and -14.8%, respectively. However, this is to a large extent a reflection of the mild weather conditions prevailing in 2014. In transport, final energy consumption is more or less constant at a marginal increase of 1.7% compared to the 2008 base year implying a very slow diffusion of energy-efficient technologies (BMWi, 2015b, pp. 33, 41). A final indicator of diffusion is the amount of conventional electricity generation capacity under construction, at least if one assumes that new, more energy-efficient conventional power plants replace older, less energy-efficient ones. This might be the case e.g., if the new plants use combined heat and power (CHP) systems or constitute pumped hydro plants that increase the storage capacity for electricity. However, conventional capacity under construction is down 57.9% compared to 2008 (BMWi, 2015b, p. 64), a reflection of the significantly reduced investment returns from conventional power plants (Sensfuß, Ragwitz, & Genoese, 2008).

Lastly, the annual investments into the expansion of the grid infrastructure have moved upwards since 2008 with a slight increase of the investments of distribution system operators (DSOs) by 11.1% compared to 2008, and a significant increase of the investments of transmission system operators (TSOs) by 77.9% compared to 2008 (BMWi, 2015b, p. 84). This may suggest that the grid infrastructure is being modernized at a higher rate and with it new technology is adopted in the grid network. However, the monitoring report admits that

[1] Directive 2009/125/EC of 21 October 2009 for Ecodesign, Directive 2010/30/EU of 19 May 2010 for Energy Labelling

transmission grid expansion is lagging behind the path what was anticipated by the 2009 Energy Grid Expansion Act (Energieleitungsausbaugesetz, EnLAG) (BMWi, 2015b, p. 79).

Table 5: Energiewende monitoring report 2014 indicators for diffusion

Area	Indicator	2014	2020 target
Renewable Energy	Share of RES in gross final energy consumption in %	13.5%	18%
	Share of RES in gross electricity consumption in %	27.4%	>35%
	Share of RES in heating in %	12.4%	14%
	Share of RES in transport in %	5.6%	not defined
Energy Efficiency	Primary energy consumption compared to 2008 in %	-8.7%	-20%
	Final energy productivity growth per year in %	1.6%	2.1%[1]
	Gross electricity consumption compared to 2008 in %	-4.6%	-10%
	Final electricity productivity growth per year in %	3.3%	not defined
	Primary energy consumption in buildings compared to 2008 in %	-14.8%	not defined[2]
	Heat consumption in buildings compared to 2008 in %	-12.4%	-20%
	Final energy consumption in transport compared with 2005 in %	1.7%	-10%
	Conventional electricity generation capacity under construction compared with 2008 in %	-57.9%	not defined
Grid infrastructure	Growth of investments by DSOs compared to 2008 in %	11.1%	
	Growth of investments by TSOs compared to 2008 in %	77.9%	

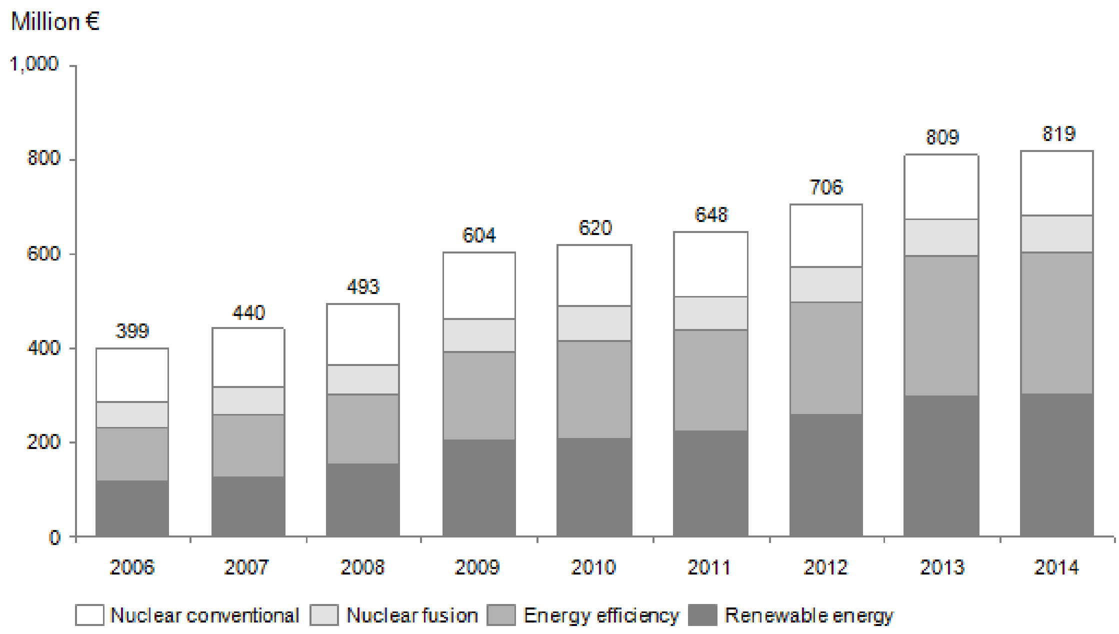
1. Growth target per year from 2008 to 2050 2. 2050 target -80%

Source: Adapted from BMWi (2015b)

Regarding invention and innovation in the dedicated innovation sections, the official government reports primarily describe the innovation support mechanisms that have been installed by the federal government such as research programs with subsidies or grants, loan programs and communication and exchange platforms. The evaluation of the innovation effect is not consistent throughout the reports as indicators change from one reporting year to the next. The main focus is on the development of federal R&D expenditures for energy research, which is presented in every report, and indicates that these have been rising since 2008, as shown in Figure 9. Patent applications, which are reviewed through various patent indicators in the reporting years 2011, 2012, and 2013, also exhibit a positive tendency. For example, international energy technology patent applications filed by German entities have risen considerably since 2003, with an especially strong increase in energy storage patents since 2009, as depicted in Figure 10. The authors of the report interpret this as a sign that the federal government efforts have spurred innovation across a variety of energy technologies (BMWi, 2014c, p. 83f). Furthermore, another manifestation of innovation activities is seen in the increasing number of new companies in the energy sector. According to the 2014 progress report, the number of new companies founded in the energy sector tripled between

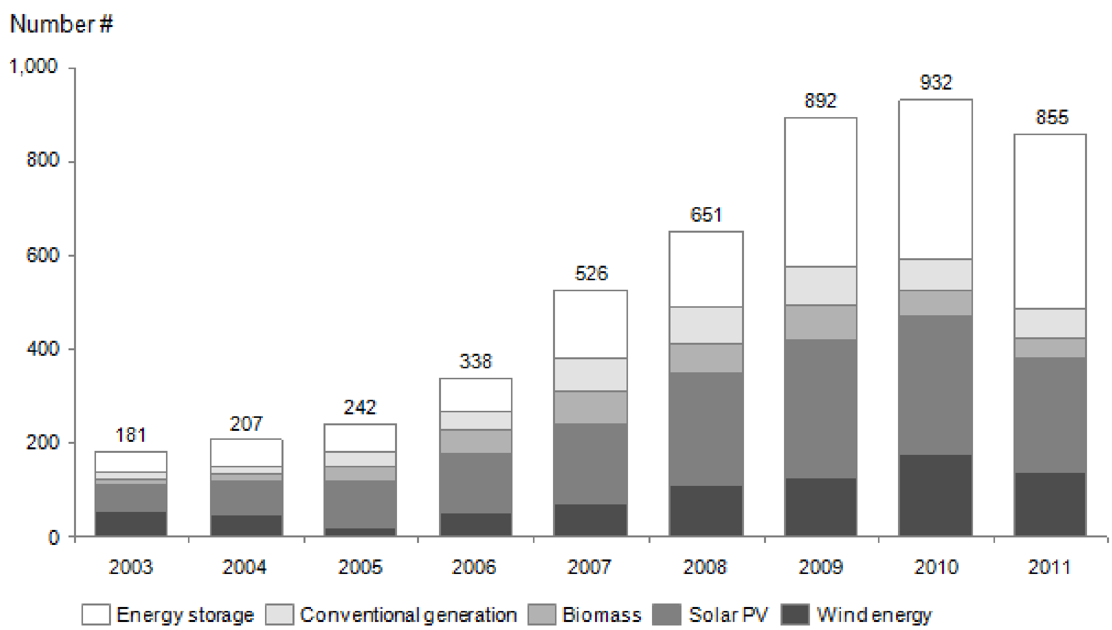
2003 and 2010 indicating increasing dynamics through the changes to the industry structure and the novelties that these firms develop and bring to the market (BMWi, 2014c, p. 84f).

Figure 9: Expenditures of the Energy Research Program 2008-2014



Source: BMWi (2015a)

Figure 10: German international patent applications across different energy technology areas 2003-2011



Source: BMWi (2014a)

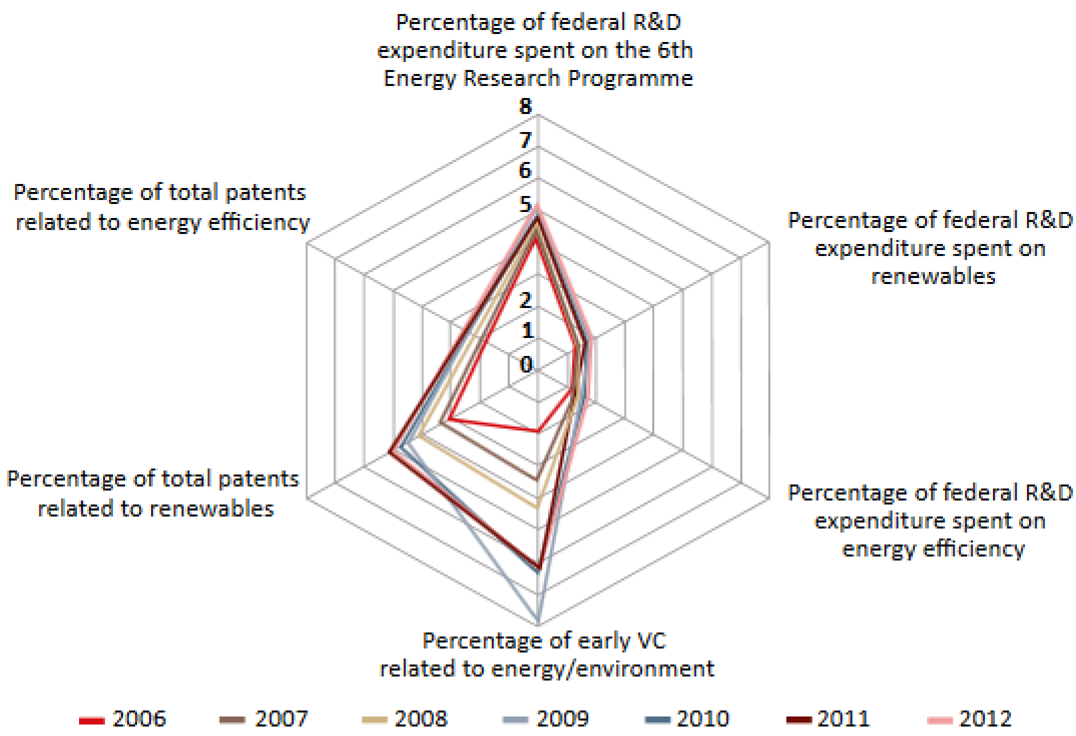
The expert commission that evaluates the official monitoring reports attributes great importance to the innovation effect of Energiewende in its statements. Regarding diffusion, the statements take account of the positive tendency that is depicted in the monitoring reports for RES, energy efficiency and grid infrastructure. However, especially the most recent statement for the year 2014 is highly skeptical of the alleged progress and expresses severe concerns regarding the possibility to achieve 2020 targets in many areas. The commission holds that in RES-E Germany is on track to meet 2020 targets thanks to the EEG, but is critical regarding the progress of RES in heating and transport. Despite the small improvements it claims that progress is largely stagnating and calls on the federal government to intervene to ensure target achievement (Löschel et al., 2015, p. 23ff). It is also highly critical of the alleged progress regarding energy efficiency. It challenges the monitoring report's positive statements regarding the decline in overall energy consumption and merely acknowledges a positive development in electricity and heating. Moreover, it holds that improvements regarding energy efficiency are not on track to meet 2020 targets. For example, to meet 2020 targets final energy productivity would need to improve by 3% annually from 2015 on, instead of the 1.6% annual improvement reported in the 2014 monitoring report for the period 2008 to 2014 (Löschel et al., 2015, p. 40). Also regarding grid infrastructure, the experts warn that the grid expansion that has taken place to date is still falling short of what is required for a successful energy transition and urge on action in this area (Löschel et al., 2015, p. 75).

Regarding innovation besides diffusion, the experts propose several instruments and indicators for a holistic assessment that goes beyond the monitoring reports' review of public R&D expenditures and patents. Holding that innovation is a multi-faceted phenomenon that cannot be captured in a single indicator it proposes a set of six indicators to measure the innovation activity induced by Energiewende. The indicators are relative measures that evaluate federal research expenditures, patent applications and venture capital volumes relevant to Energiewende in relation to the respective data not relevant to Energiewende[1]. Figure 11 shows the development of the six indicators from 2008 to 2012 as presented by the

[1] The six indicators are: percentage of federal R&D expenditure spent on the 6th Energy Research Programme, percentage of federal R&D expenditure spent on renewables, percentage of federal R&D expenditure spent on energy efficiency, percentage of total patents related to energy efficiency, percentage of total patents related to renewables, and percentage of early venture capital related to energy/environment (Löschel, Erdmann, Staiß, & Ziesing, 2014a, p. 24).

expert commission (Löschel et al., 2014c, p. 24). Since 2006 the relative importance of energy research, as well as the importance of renewables and energy efficiency in terms of R&D expenditures and patents has increased. Venture capital in the areas of energy and environment spiked in relative importance in 2009 but subsequently decreased again, while staying significantly above 2006 levels (Löschel et al., 2014c, p. 186f). While these indicators show a positive tendency for Energiewende related innovation, the impact of Energiewende policies on these, however, is not explicitly investigated.

Figure 11: Energiewende monitoring expert commission's innovation indicators 2006-2012



Source: Löschel et al. (2014a, p. 24).

To address this shortcoming a number of qualitative statements are made regarding the innovation effect of Energiewende policies. First, the expert commission claims that Energiewende has triggered dynamics that have increased innovation activity, albeit with "heterogenous transmission mechanisms" (Löschel, Erdmann, Staiß, & Ziesing, 2014b, p. Z-21). One such dynamic was set off by the EEG as the market growth in renewable energy attracted private investments into the technological development of RES technology (Löschel, Erdmann, Staiß, & Ziesing, 2012, p. 111f). Technological progress together with rising production capacity resulted in economies of scale and learning and therefore large cost reductions for RES. In photovoltaic (PV), for example, the experts estimate that costs per installed capacity would be ~30% higher today without the EEG mechanism. In a rough cost-benefit-assessment the experts also stipulate that the global cost reductions in 2012 exceeded the costs of the EEG in the same year about 5 times (Löschel et al., 2014b, p. 170). The expert commission notes that it would be worthwhile to investigate innovation activities on the firm level instead of using aggregate figures, but regrets that data for such enquiries is not available at present (Löschel et al., 2014c, p. 190).

4.2 Academic research on the innovation effect of Energiewende

Besides the official monitoring process an investigation of the innovation effect of Energiewende also takes place through academic publications. By far the largest number of contributions to the topic is concerned with innovation regarding electricity from renewable energy sources (RES-E). In addition, also innovation in RES heating and transport (RES-H and RES-T, respectively), energy efficiency, grid infrastructure and organizational topics is examined. There are few empirical studies that investigate the effect of Energiewende or German energy policy on innovation in particular. However, a large number of studies touches upon the topic or is relevant to it, as presented below. The literature review in the following sections is therefore not exhaustive, but highlights key contributions, interesting findings and important debates in terms of empirical investigations and reviews thereof. An overview and comparison of the publications presented as part of the literature review can be found in Table 6.

4.2.1 Innovation in RES-E

When discussing the innovation effect of Energiewende, the focus is most of the time exclusively on innovation around electricity from renewable energy sources (RES-E). Studies investigate the effect of single policies, such as the EEG, or policy mixes combining various policy instruments. One can distinguish between studies on the impact on the diffusion of technology for RES-E and studies regarding the lateral effect on further technological development i.e. invention and implementation of RES-E technology.

4.2.1.1 Diffusion

Regarding the diffusion of RES-E, there is a broad consensus that the German feed-in-tariffs (FITs) for RES-E, installed by the 1990 StrEG and then especially the 2000 EEG, have driven the wide spread of RES-E generation technology. Germany is among the top countries in Europe when it comes to the deployment of wind onshore, solar PV, and biomass technology for electricity generation. The fact that it is political intervention that has caused the rise of RES-E is so universally accepted that just for Germany hardly any studies exist. In fact, many publications label RES-E installations as "politically-induced market growth" when they investigate the consequences of such deployment on other factors (Böhringer et al., 2014; Cantner, Graf, Herrmann, & Kalthaus, 2014; Hoppmann et al., 2013; Nemet, 2009; Wangler, 2012). Studies that investigate the effect of policies on the diffusion of RES-E technology usually do so across countries. The overwhelming result is that diffusion took place and German deployment policies, especially the StrEG and EEG, were instrumental in driving this diffusion.

Comparing policy strategies for the promotion of RES-E deployment across European countries, Held, Ragwitz, & Haas (2006) and Haas et al. (2011b) find that Germany's feed-in tariffs for RES-E (FITs) are among the most effective in terms of incentivizing the diffusion of RES-E technology. They develop an effectiveness indicator by calculating the change of RES-E electricity generation between two points in time in relation to the natural generation potential in the absence of a support mechanism. The effectiveness indicator for Germany between 1990 and 2005 is given at 9%, the second highest following Spain. They argue that this is the case because fixed technology-specific FITs provide investors with high investment security and a low administrative burden. They furthermore hold that RES-E deployment was achieved in an economically efficient way at the lowest possible cost to society as the generation output is comparatively high given the moderate support level of Germany's FIT. This result is upheld by subsequent updates to the study and official European Commission progress reports using the same indicator (Klessmann et al., 2011).

Using panel data from 26 European countries, Jenner, Groba, & Indvik (2013) investigate the effect of FIT tariff strength on annual RES-E capacity additions. Interestingly they find that the FIT interacts with other variables in determining the growth of RES-E capacity. It is not the absolute rate of the FIT or the installation of an FIT as such that predicts capacity additions, but rather the return that investors can expect on their RES-E investment, which they capture in a self-developed indicator that combines FIT rate, electricity price, and electricity production costs. This indicates that it is not an FIT as a policy by itself, but rather its design and the incentive this constitutes for the investor that creates success in terms of RES-E deployment. Several publications also find that the strength of FITs lies in their ability to provide attractive returns and risk reduction to investors (Bürer & Wüstenhagen, 2009; Mitchell, Bauknecht, & Connor, 2006).

4.2.1.2 Invention and innovation

In contrast to diffusion where the political impact is largely clear, a much stronger debate on the innovation effect of Energiewende policies on RES-E arises when it comes to the earlier stages of the innovation process i.e. the invention, development and implementation of novelties.

Wangler (2010, 2012) studies the effect of policy-induced growth of installed RES capacity on the number of patent applications in PV, wind, biomass, hydro, and geothermal in Germany between 1990 and 2005. They find a significant positive relationship between such market growth, as well as public R&D expenditures, and the number of patents filed across the five technologies PV, wind, biomass, hydro and geothermal. However, they also find significant differences between the technologies. The overall positive effect is only due to a large positive effect in wind. Nevertheless, they overall conclude that both the EEG as well as the StrEG had a positive effect on innovation.

Building on Wangler's work, Böhringer et al. (2014) investigate the correlation between the EEG and StrEG feed-in-tariffs (FITs) and patent applications in two different models across the same five RES-E technologies. In the first model, using the FIT rate i.e. € compensation per kilowatt hour of RES-E fed into the grid as an independent variable, they do not find a significant, positive relationship to patent applications in 2000 to 2009. In the second model, using installed capacity as an independent variable, they obtain somewhat different results. They find a positive, significant effect across all RES technologies over the combined StrEG and EEG periods from 1990 to 2009, as well as the EEG period 2000 to 2009 by itself. Similar to the findings of Wangler (2010, 2012), however, distinguishing by RES-E technology results in mixed effects. A significant positive effect exists only for wind, the effect is insignificant for PV and geothermal, and even negative for biomass and hydro. They conclude that there is insufficient evidence for a positive innovation effect of the EEG. They argue that strong policy-induced market growth may incentivize shift of resources from risky exploratory research to activities that exploit mature technologies, raise market barriers for new entrants and lock-in established technologies (Böhringer et al., 2014, p. 11). The authors conclude that there is insufficient evidence.

Another study has attempted to grasp the effect of the German promotion of RES-E on innovation by comparing Germany's share of RES patents and R&D expenses relative to other countries. Bointner (2014) studies Germany's share of the global renewable energy knowledge stock defined as cumulative public R&D expenditures and patents until 2012 in comparison to other countries. They find that Germany is leading in terms of RES patents per GDP, and middle range in terms of public R&D expenditure for RES per GDP. While they do not empirically test the relationship of these shares to a policy measures they regard these findings as an effect of German energy policy overall.

Looking beyond only the EEG, Breitschopf (2015) investigates the relationship between a policy mix represented through a number of variables incl. the financial attractiveness of the EEG, RES deployment targets, public R&D spent, and investment support, on market formation and technological competitiveness expressed through patent applications from the 1980s to 2010. She finds that patents are directly influenced by the financial attractiveness as well as public R&D spent. Furthermore, financial attractiveness drives market formation, which moreover positively influences the patent count. She hence presents a positive picture of the innovation effect of FITs with a direct and an indirect dynamic.

Also Reichardt and Rogge (2015) are interested in the innovation effect of a policy mix rather than individual policies. The authors examine the effect of the energy policy mix on RD&D in offshore wind technology through a series of qualitative case studies. Comparing various elements of the policy mix they find that policy strategy i.e. the articulated vision and long term targets regarding the deployment of offshore wind, and policy instruments consistently implementing that strategy have a positive effect on RD&D.

The studies reviewed so far have explicitly focused on Germany, or have compared Germany with other countries. In addition, a number of influential studies have investigated the effect of policy instruments on patents at an aggregate level across countries (including Germany) and derived general conclusions regarding their effectiveness that also contain an evaluation of German policies to some extent (Dechezleprêtre & Glachant, 2014; Emodi, Shagdarsuren, & Tiky, 2015; Johnstone, Haščič, & Popp, 2010; Peters, Schneider, Griesshaber, & Hoffmann, 2012; Walz, Schleich, & Ragwitz, 2011). All studies generally confirm that public policy is crucial for innovation in RES-E. However, most studies find significant differences in effectiveness across policy instruments and RES-E technologies, ranging from significant positive to significant negative effects. There is unanimity regarding the positive effect of policy-induced market growth i.e. RES-E generation, or the installation of RES-E generation capacity, on patents (Dechezleprêtre & Glachant, 2014; Emodi et al., 2015; Johnstone et al., 2010; Walz et al., 2011). However, regarding a direct effect of the FIT rate on patents findings vary. Johnstone et al. (2010) find a positive effect only on patents in solar, whereas Emodi et al. (2015) do not find an effect at all. In contrast, technology-specific public R&D is widely identified as a positive driver of patenting (Johnstone et al., 2010; Peters et al., 2012; Walz et al., 2011), except by Emodi et al. (2015). Also RES-E deployment targets are generally found to have a positive effect (Johnstone et al., 2010; Walz et al., 2011).

Reviewing the results of several of these publications on the effect of the EEG on patents, the expert commission for research and innovation installed by the German federal government (EFI) concludes that the German EEG did not increase innovation activities (EFI, 2014). The commission argues that studies with a focus on Germany such as Wangler (2012) and Böhringer (2014) do not find sufficient evidence for a positive impact of the EEG on patent applications across RES technologies. Moreover, the positive effects observed in international comparisons such as Johnstone et al. (2010), Walz et al. (2011), Peters et al. (2012), and Dechezleprêtre & Glachant (2013) are aggregate effects across countries with observation periods often not coinciding with the duration of the EEG, which was only installed in 2000. The EFI follows Böhringer's (2014) line of reasoning to hold that as a flat subsidy that is levied irrespective of the costs of the underlying technology it does not provide sufficient incentives for technology providers to invest in risky technological exploration. Indeed it could have an opposite effect and lead to declining investment in R&D if technology providers exploit the current market opportunities through investments in production capacity instead. Frondel et al. (2010) make a similar argument. They maintain that the technology-specific FIT rates of the EEG prevent a do price competition between RES technologies and that the declining FIT rates over time that are inherent in the EEG incentivize early adoption of premature technology over technological improvement.

This view is contested by Ragwitz et al. (2014), a group of 17 researchers around the Fraunhofer Institute for Systems and Innovation research (ISI), which released an expert statement on the innovation effect of the EEG. The statement contends that the EEG had a positive effect on innovation activity, but an effect that due to its breadth cannot be adequately captured by looking only at patents. According to the group, innovations are a result of several influencing factors and an analysis of the innovation effect of the EEG needs to be embedded in its context in order to be meaningful. Five arguments for a positive innovation effect of the EEG are advanced:

1. Besides the fact that patents in RES technology have been rising since the 2000s, patents are only an indicator for a certain part of technological innovation, namely technological invention. On the one hand, many innovations, especially non-technological ones, are not patented, on the other hand, even if patented not all inventions are commercialized and widely adopted.
2. The demand for RES technology created through the EEG has contributed to technological development as well as learning and scale effects that have decreased the costs and increased the performance of RES technology.
3. Through the increased demand for RES technology, demand has also increased for complementary technology and other elements of the energy system that are affected by the rise of electricity generation from RES, such as electricity grids and energy storage, and in turn positively influenced innovation there.
4. The EEG has also brought about organizational and institutional novelties e.g., regarding the financing of electricity generation capacity and the enablement of small actors within the energy system.
5. Fifth, the EEG has created innovation outside Germany through technological spillover in international value chains and networks as well as the imitation of EEG-type policies in other countries.

With a similar line of argumentation, two other researchers, Rennings & Rexhäuser (2014), criticize the EFI's sole focus on patents as indicators of an innovation effect. They argue that first, not all innovations are patented and second, that patents only indicate the invention stage of the innovation whereas for the success of the Germany energy transition, the commercialization of innovations and their diffusion are equally important.

Looking at the effect of RES-E deployment for the energy system as a whole, Strunz (2014) argues that the German energy transition constitutes a socio-technical regime shift from a "fossil-nuclear to a RES-based regime" (Strunz, 2014, p. 157). Using the conceptual framework of the "resilience" (Walker, Holling, Carpenter, & Kinzig, 2004) of a system i.e.

the "capacity of a system to absorb disturbances" (Strunz, 2014, p. 151) he argues that the fossil-nuclear energy system lost its resilience in Germany when the environmental movement succeeded in gaining political support and breaking-up the ties between proponents of the fossil-nuclear system and political decision-makers. The Fukushima accident in 2011 then initiated the regime shift by causing an "exogenous disturbance" (Strunz, 2014, p. 154) that the fossil-nuclear system could not compensate for anymore. The future pathway for Energiewende now is to create resilience in an RES-based energy system.

Regarding the innovation effect of the 2011 post-Fukushima political decisions and the popular adoption of the term Energiewende, Rennings & Rexhäuser (2014) allege that due to a time delay in firm-level innovation surveys, one needs to wait until relevant firm level data on innovation activity becomes available.

Table 6: Selected empirical investigations and literature reviews regarding an innovation effect of Energiewende policies

Area	Author, Year	Energiewende indicator	Innovation indicator	Research design
RES-E diffusion	**Held, Ragwitz, & Haas (2006)**	• FIT	• RES-E generation	• Comparative country case studies with a quantitative indicator • EU 15 countries, 1998-2005 • Wind onshore
	Haas et al. (2011)	• FIT	• RES-E generation	• Comparative country case studies • EU 7 countries, 2003-2008 • I.a. wind, solar PV, biomass, geothermal
	Jenner, Groba, & Indvik (2013)	• FIT	• RES-E capacity installed	• Econometric cross-country study • EU 26 countries, 1990-2006 • Wind onshore, solar PV
RES-E invention and innovation	**Wangler (2010, 2012)**	• RES-E capacity installed	• Patents	• Econometric single country study • Germany, 1990-2005 • Wind, solar PV, hydro, geothermal, biomass
	Böhringer, Cuntz, Harhoff, & Otoo (2014)	• FIT rate • RES-E capacity installed	• Patents	• Econometric single country study • Germany, 1990-2009 • Wind, solar PV, hydro, geothermal, biomass
	Bointner (2014)	• Promotion of energy technologies	• Patents • Public R&D	• Econometric cross-country study • Germany, Japan, US, Austria, 1974-2012 • 7 energy technologies (energy efficiency, fossil fuels, renewable energy, nuclear, hydrogen, fuel cells, energy storage)
	Breitschopf (2015)	• Policy mix incl. FIT, RES-E deployment targets, public R&D	• Patents	• Econometric single country study • Germany, 1980s-2010 • Solar PV
	Reichardt & Rogge (2014)	• Policy mix incl. vision, RES-E deployment targets	• RD&D • Adoption[2]	• Comparative company case studies • Germany, 2000s to 2013 • Offshore wind
	Johnstone et al. (2010)	• Various policy instruments incl. public R&D , deployment targets	• Patents	• Econometric cross-country study • 25 OECD countries incl. Germany, 1978-2003 • Wind, solar, geothermal, biomass, waste, ocean
	Walz et al. (2011)	• Various policy instruments incl. public R&D, deployment schemes	• Patents	• Econometric cross-country study • 12 OECD countries incl. Germany, 1991-2007 • Wind
	Emodi, Shagdarsuren, &	• Various policy instruments incl. public	• Patents	• Econometric cross-country study • 12 OECD countries incl. Germany, 1997-2011

	Tiky (2015)	R&D, FIT, RES-E generation		• Wind, solar
	Peters , Schneider, Grießhaber, & Hoffmann (2012)	• Foreign v. domestic tech.-push policy (public R&D) and demand-pull policy (REC-E capacity installed)	• Patents	• Econometric cross-country study • 15 OECD countries incl. Germany, 1978-2005 • Solar PV
	Dechezleprêtre & Glachant (2014)	• Foreign v. domestic demand-pull policy (RES-E generation)	• Patents	• Econometric cross-country study • 28 OECD countries incl. Germany, 1991-2008 • Wind
	EFI (2014)	• FIT	• Patents	• Literature review • Germany and cross-country, 2000-2014 • RES-E technologies
	Frondel, Ritter, Schmidt , & Vance (2010)[1]	• FIT	• RES-E generation & capacity inst., • Incentive to improve technology	• Single country case study • Germany, 1990-2008 • Wind onshore, solar PV, biomasss
	Ragwitz et al. (2014)	• EEG	• Innovation dynamics	• Literature review • Germany, 2000-2014 • RES-E and complementary technologies
	Strunz (2014)	• Post-Fukushima political decisions	• Renewable-based energy system	• Qualitative case study • Germany, 1950s-today • RES-E technologies
	Rennings & Rexhäuser (2014)	• Energiewende policy mix	• Patents • Innovation dynamics	• Literature review and case study • Germany, 1990s-2014 • RES, energy efficiency
RES-H/T	**Klessmann, Held, Rathmann & Ragwitz, (2011)**[1]	• Various policy instruments incl. FIT, obligations,	• RES-E generation & capacity installed • RES-H deployment • RES-T deployment	• Comparative country case studies with a quantitative indicator (updated from Held et al. 2006) • EU 27 countries, 1998-2005 • Wind onshore, wind offshore, solar PV, solar thermal, biomass, biogas, biofuels, geothermal
	Marth & Breitschopf (2011)	• Policy mix incl. obligations	• Incentive to improve technology	• Qualitative expert interviews • Germany, 2000s to 2010 • Micro combined heat and power (CHP)
	Steinhilber, Wells & Thankappen (2013)	• Various	• RES-T deployment	• Comparative country case studies • Germany and UK, 2000s-2012 • Electric vehicles
Energy efficiency	**Horbach, Rammer, & Rennings (2012)**	• Various policy instruments incl. public R&D, standards, limits	• Introduction of innovations	• Econometric single country study • Germany, 2008 • Energy-efficiency across industries, i.a.
	Rexhäuser & Löschel (2014)	n/a	• Patents	• Econometric single country study • Germany, 2000-2009 • RES v. energy-efficiency across industries
Grid infra-structure	**Römer, Reichart, Kranz, & Picot (2012)**	• Various	• Implementation of smart grid technology	• Qualitative expert interviews • Germany, 2000s-2011 • Smart grids, smart meters, energy storage
	Muench et al. (2014)	• Various	• Implementation of smart grid technology	• Qualitative expert interviews • Germany, 2000s-2013 • Smart grids
Organization and business model	**Bontrup & Marquardt (2015)**	• Electricity market liberaliation and Energiewende policy mix	• Corporate strategy, performance and organization	• Comparative company case study • Germany, 1998-2014 • Big four electricity suppliers
	Kungl (2015)	• Electricity market liberaliation and Energiewende policy mix	• Corporate strategy, actions	• Comparative company case study • Germany, 1998-2013 • Big four electricity suppliers
	Richter (2013)	• Energiewende policy mix	• Business models	• Qualitative elite interviews • Germany, 2000s-2012 • Electricity suppliers
	Wassermann et al. (2015)	• EEG	• Corporate strategies • Business models	• Qualitative single sector case study • Germany, 2000s-2013 • Electricity suppliers, energy services
	Cantner, Graf,	• Policy mix incl. RES-E	• RES-E inventor	• Econometric single country study

	Herrmann, & Kalthaus (2014)	installed capacity, public R&D	networks	• Germany, 1980s -2011 • Wind, solar PV
	Ketata, Sofka, & Grimpe (2015)	• Regulatory pressure for sustainability	• Sustainability innovation capabilities	• Econometric single country study • Germany, n.d. • Manufacturing sector
	Makowski, Wu, Yagi, & Kokubu (2015)	• Post-Fukushima political decisions	• GHG emissions	• Econometric study, panel data regression • Germany and Japan, 2006-2012 • All sectors

4.2.2 Innovation beyond RES-E

Contributions to the study of the impact of Energiewende on innovation beyond RES-E are rare and typically confined to single industry or single technology case studies. Overall the impact of policies here is less clear than the overall positive picture that emerges, despite the debate, from innovation in RES-E.

4.2.2.1 RES in heating and transport

RES do not only play a role in electricity, but also in the other uses of energy, heating and transport. There is little research on policy effectiveness in either area, possibly because both types of energy have been less in political focus than electricity and RES are still of comparatively minor importance in both. Studies in the field typically examine technological feasibility or potential, and indicate the need for further political support rather than evaluate its effectiveness. Similar to what is stated in the official monitoring reports, also independent researchers find that the deployment of RES in heating (RES-H) and transport (RES-T) clearly lacks behind electricity due to being of lower political priority (Klessmann et al., 2011).

Nevertheless, there are a few contributions regarding renewables in heating. Investigating the effectiveness of RES-H support schemes across the EU, Klessmann et al. (2011) find that an obligation to employ RES in heating as installed in Germany by the 2009 Renewable Energy Heating Act (EEWärmeG) is one of the best policy instruments to incentivize the deployment of RES-H in European comparison. The positive impact of the EEWärmeG obligation is, however, limited by the exceptions that are granted. Another in-depth investigation is Marth & Breitschopf's (2011) study on the innovation effect of a policy mix in combined heat and power (CHP) in Germany[1]. Using expert interviews to assess the influence of firm-internal factors, market factors and political factors on innovation activities

[1] Since CHP combines heat, electricity, and the notion of energy efficiency, this study is also relevant for the respective other sections of this literature review.

in micro-CHP, they find, however, that the political influence is ambiguous at best. In general technology providers welcome policies that boost the market for CHP, such as the Combined Heat and Power Act (Kraft-Wärme-Kopplungsgesetz, KWKG) and the Renewable Energy Heating Act (EEWärmeG) claiming that diffusion subsidized by these instruments also provides incentives for them to invest in further technological development. The KWKG, however, is not considered powerful enough. The EEWärmeG sent some positive impulses by mandating the use of renewable energy for heating in new buildings. However, the positive effect of these instruments on innovation is offset by other regulations, which erect administrative and technical barriers to micro-CHP deployment. Regulations regarding the technical installation of micro-CHP systems as well as registration and accounting guidelines limit the attractiveness of micro-CHP as a heating solution.

There is even less literature on the effectiveness of Energiewende policies regarding renewables in transport. RES-T is a wide area that encompasses different transport modes such as sea, air, rail, and road transport, as well as different possible RES energy carriers in each of these transport modes, such as biofuels, biogas, power-to-gas from RES, hydrogen fuel cells, or RES-E (cf. Chapman, 2007; Geels, 2012). Reviewing literature from all these areas is not in the scope of this thesis. Based on common knowledge and experience one can assert that policies have to date not achieved a widespread diffusion of RES carriers in any of the transport modes to such an extent that the conventional transport systems will soon be overhauled. Regarding the use of biofuels as alternative to gasoline in the combustion engines of cars and trucks, Klessmann et al. (2011) state that policy instruments such as tax exemptions and quotas can be effective for deployment, however, their efficacy depends on the strength of the incentive provided. Germany's biofuel share fluctuated throughout the 2000s when the quota was lowered in 2007, suggesting that the incentive or obligation was not strong enough (2011, p. 7647). Regarding electric vehicles, Steinhilber, Wells & Thankappen, (2013) hold that the diffusion of electric vehicles as well as their further technological development remains slow as current policies are yet not strong enough to break the predominance of the conventional individual transport system around combustion engines.

4.2.2.2 Energy efficiency

As energy efficiency is the second big pillar for the achievement of the overarching Energiewende targets after RES (Fischedick & Thomas, 2013; Löschel et al., 2014c), there is a lot of interest in researching progress and barriers towards making Germany more energy-efficient. However, similar to research in RES-H and RES-T, many studies focus on potential, instead of policy evaluations. A difficulty in reaching an overall assessment of the innovation effect of policies is that energy-efficiency is a very broad area that is difficult to scope since it is relevant to everything that consumes energy, in each of its forms. Energy-efficiency plays a role in e.g., the energy use of buildings, in electricity generation, the energy consumption of electronic products and industrial production processes. Most publications agree that the attention to energy-efficiency has increased and that politics has made a positive contribution to this, however, that a lot of untapped potential remains (cf. Fischedick & Thomas, 2013).

Horbach, Rammer & Rennings (2012) use firm-level data from the Community Innovation Survey (CIS) across a variety of industries to examine antecedents to a variety of environmental innovations incl. energy-efficiency. They confirm that the most important motivation for energy-efficiency is cost savings, however, that political interventions such as public R&D funds and standards or limits matter greatly matter for inducing environmental innovation. They argue that while in an area such as energy-efficiency where innovation results in clear financial benefits these market incentives for innovation should in theory suffice to stimulate it, political intervention may still be needed to curb market and behavioral failures (Horbach et al., 2012, p. 119f).

Rennings & Rexhäuser (2014) show that Germany has achieved technological progress in energy-efficient technologies with an increase the share of energy-efficiency patents since the mid 2000s. Comparing the characteristics of firms inventing in both technologies, Rexhäuser and Löschel (2014) find that firms who register patents for energy-efficiency are also inventors in conventional technologies. This indicates that energy-efficiency inventions take place in diversified industrial firms, whereas a lot of the patented inventions in RES technology stem from firms only focused on RES. Naturally, it is harder to research firms with diversified activities as it might not be possible to distinguish the influences on efforts and finance gone into energy-efficiency invention and innovation from influences and activities in areas less relevant to Energiewende.

4.2.2.3 Grid infrastructure

Extensions of and improvements to the grid network that takes, transmits and distributes electricity are important to cope with decentral and fluctuating electricity from renewable energy sources. Developments are needed on the physical side of the grid in terms of electricity lines and electricity storage capacity, as well as on the virtual side with grid management and tools to increase flexibility. However, academic publications tend to address technical opportunities or barriers to implementation, rather than investigating the political antecedents to the development, implementation and diffusion of such technologies.

Without explicitly mentioning the electricity grid, but very likely alluding to smart grids and energy storage, Ragwitz et al. (2014) assert that the EEG has triggered innovation activities in technologies complementary to renewable energy and required for a decentral energy system. They do, however, not go into detail regarding the exact trigger or mechanism. Römer, Reichart, Kranz & Picot (2012) investigate barriers to the diffusion of the infrastructure needed for smart grids, smart meters and decentralized energy storage, which they view as a necessity given the politically-induced high share of RES-E in Germany. They argue that in addition to insufficient economic incentives, a contradictory legal and regulatory framework impedes diffusion (Römer et al., 2012, p. 492f). Similar conclusions are reached by Muench al. (2014) in a comparable research context.

4.2.2.4 Organizational aspects

Some academic contributions investigate firm-internal organizational change triggered by Energiewende. These studies do not explicitly research the innovation impact of particular policies, but nevertheless suggest that developments that are direct or indirect consequences of Energiewende policies have lead to organizational changes in firm. The focus overall is almost exclusively on electricity suppliers, firms from other affected industry comparatively less researched.

In a study for the environmental non-governmental organization Greenpeace, Bontrup & Marquardt (2015) investigate the strategy, performance and organization of the largest four German electricity suppliers since the liberalization of electricity markets and throughout the process of energy transition. They argue that top managers have not reacted to the political changes taking place as past business success had made them inert and complacent. It was only after the 2011 Fukushima incident and the acceleration of the nuclear exit that they became serious about response strategies and the development of new business models around renewable energy, infrastructure and energy services.

Kungl (2015) examines the strategies and behaviors of the four largest German electricity incumbents against the background of the energy transition from 2008 to 2013. He finds that political and regulatory changes were the most important dynamics affecting the firms in the time period studied. While making similar observations to Bontrup & Marquardt (2015) in terms of late adaptation, Kungl argues that this was a deliberate strategic decision to defend the traditional business model. Albeit wrong in hindsight, it was not inertia, but a false interpretation of the environmental tendencies that drove it (Kungl, 2015, p. 31f).

Regarding the business models of electricity suppliers, Richter (2013a, 2013b) argues that Energiewende, in particular the decentralization of the electricity system that was brought about by the rise of RES-E, has affected electricity suppliers in such a way that they were forced to develop new business models for the supply of renewable energy. In a similar direction, Wassermann et al. (2015) examine how actors are developing a service offering for the direct marketing of RES-E, a provision of the 2012 EEG amendment, based on re-organization, collaboration and competition.

Looking beyond electricity suppliers, Cantner, Graf, Herrmann & Kalthaus (2014) investigate the influence of the German policy mix on corporate inventor networks in renewable energy since the 1980s. They find that policies influence the way that firms work together in the innovation process. Policy-induced growth in installed RES capacity drives the average number of cooperations that firms have as well as the total number of firms cooperating. Public R&D expenditures and consortium-based research grants also drive the total number of firms cooperating in RES. Policy instruments have hence time positively influenced innovation activities in terms of cooperation.

Using data on the manufacturing sector taken from the German Community Innovation Survey (CIS), Ketata, Sofka and Grimpe (2015) examine how firms develop capabilities required for sustainable innovation, defined as innovation for the reduction of resource- and energy consumption, economic stress and improvements in health and safety. They find that regulatory pressure towards sustainability increases the development of these capabilities. While it is not the most important factor, investments in employee trainings are, it is a significant predictor of sustainable innovation capabilities. This suggests that political influence manifests itself in organizational features on the firm level such as, in this study, organizational capabilities.

Lastly, Makowski, Wu, Yagi & Kokubu (2015) investigate corporate greenhouse gas (GHG) emissions in Germany and Japan before and after 2011, the year of the Fukushima nuclear incident in Japan, to find out if the respective political decisions taken immediately after the incident had an effect on firms in terms of emission reduction. They do not find this to be the case in Germany as the GHG intensity pre- and post-2011 remains virtually unchanged.

4.3 Three research gaps and three controversies

The preceding literature review shows that an investigation of the innovation effect of Energiewende is not completed yet. There are good reasons and some, albeit contested, evidence to suggest that the policies associated with Energiewende have affected innovation activities in RES-E and beyond. While there seems to be agreement on some topics there are controversies regarding other aspects. There are also research gaps when it comes to how the innovation effect of Energiewende has hitherto been studied. Three research gaps and three controversies are particularly prominent.

Despite the great variety of studies on the innovation effect of Energiewende, three gaps in empirical research emerge in particular: research with an understanding of Energiewende as a complex transition process, a broad definition of innovation, and firm-level investigations.

First, there is a *lack of empirical investigations that understand Energiewende as a complex transition process*. Some publications, at least many of the empirical ones, view Energiewende only through one particular policy, such as the EEG, or even only a part of it, such as a feed-in-tariff. While the EEG is certainly a core policy, looking at it exclusively and without its context does not capture the transformative aspects that Energiewende has taken on as a policy mix and a process that evolved over time. A comprehensive study of the Energiewende's innovation effect requires a more integrated understanding of Energiewende that considers the entire policy mix incl. interactions between different policies, interactions with other influencing factors and changes over the course of the process.

Second, there is a *lack of empirical research that employs a broad definition of innovation*. Many of the studies implicitly only focus on a particular stage of the innovation process, such as invention. Patents, for example, are an output indicator for the invention stage. Schumpeter and others, however, argue convincingly that the innovation process involves multiple steps including the implementation as well as the diffusion of new ideas (cf. section 2.1.1). In order to capture the innovation effect of the energy transition in its entirety, innovation hence needs to be considered from the early stages of idea inception to the dissemination of a novelty throughout an industry or economy. This also involves studying technological as well as non-technological innovation, and various sectors relevant to the energy system, not just electricity.

Third, there is a *lack of empirical research on the firm level*. Although there is an agreement that firms are the most critical actors in the innovation process (cf. section 2.1.4) most studies do not investigate firms, but rather use aggregate data such as patents to capture the results of corporate innovation activities. Such data is conducive to academic research as it is accessible through public databases, available in large quantities and suitable to comparisons. Data on the firm level is much harder to obtain and interpret, especially for diversified firms where the activities relevant to innovation in the context of Energiewende only constitute a part of all innovation activities, and may not be specifically tracked. Some empirical studies cited above (Horbach et al., 2012; Rennings & Rammer, 2009; Rexhäuser & Löschel, 2014) rely on data from the Mannheim Innovation Panel (MIP), a systematic collection of panel data from about 6,000 German firms conducted annually as part of the German contribution to the EU Community Innovation Survey (CIS). However, published every January for the calendar year two years in advance, CIS/MIP data becomes available with a time lag of at least 1.5 years. The latest data set published in January 2016 contains information on corporate innovation activities in the year 2014 (Rammer et al., 2016). Until academic contributions using this data become available a further delay is incurred. This means that data for the years after 2011, which is of special interest following Fukushima and the accelerated Energiewende, is only available for three years now and has not been analyzed to that end yet. Current investigations of innovation on the firm level hence need to conduct their own data collection, such as done by a few of the contributions reviewed in the form of qualitative case studies. As explained above, also the expert commission of the official monitoring process recommends data collection and the investigation of innovation activities on firm level (Löschel et al., 2014b).

In addition to these research gaps, the literature exposes several controversies when it comes to assessing the innovation effect of Energiewende. The three most striking ones pertain to the innovation impact of the EEG, the innovation impact of the accelerated Energiewende post-Fukushima, and the impact of the Energiewende policy mix on organizational innovation within firms.

First, there is a very lively academic debate regarding the *innovation impact of the EEG*. Contentious since its installation, controversy also persists in the assessment of its effect on innovation, especially when it comes to the invention and implementation of novelties. As elaborated above (cf. section 4.2.1.2), two groups of researchers come to almost diametrical results. While the first group, experts around the federal government's expert commission for research and innovation (EFI), negate a positive effect of Energiewende on innovation based mainly on innovation in RES-E and patents as an innovation indicator (Böhringer et al., 2014; EFI, 2014; Frondel et al., 2010), the Energiewende monitoring process expert commission and researchers from the Mannheim-based Center for European Economic Research (Zentrum für europäische Wirtschaftsforschung, ZEW) and Fraunhofer ISI claim a positive impact, and one that goes beyond patents and RES-E (Löschel et al., 2014b; Ragwitz et al., 2014; Rennings & Rexhäuser, 2014; Rexhäuser & Löschel, 2014). Solving this controversy is relevant in the wider academic debate on the innovation effect of demand-pull policy instruments (cf. section 2.2.2.2) as well as for policy makers in Germany and beyond.

Second, there is a controversy regarding the *impact of the post-Fukushima "accelerated Energiewende"* that was initiated by the fall 2011 political decisions to shorten the remaining life time of nuclear power plants while maintaining the ambitious targets pertaining to GHG emissions, RES deployment and energy efficiency. As the term *Energiewende* as an object of popular discourse was only introduced following these decisions (cf. section 3.3.4), and the mainstreaming has some authors argue that this development has concentrated innovation efforts and specifically triggered major changes among electricity suppliers (Bontrup & Marquardt, 2015; Kungl, 2015). Strunz (2014) sees the post-Fukushima decisions as the critical element that finalized a "regime shift" (2014, p. 153) from a fossil-nuclear to an RES-based energy system and therefore positioned firms to focus their activities on succeeding in the new energy system. Others do not attribute 2011 any special significance in comparison to political interventions and the transition of the energy system that had been ongoing since years before (Böhringer et al., 2014; EFI, 2014). Getting a better understanding of the actual impact of 2011 in terms of innovation is central to the federal government that was at time heavily criticized for its allegedly rash decision to reverse the life time extension for nuclear power plants that had been passed less than a year in advance. Clearly the federal government views 2011 as a turning point that deems recognition; the Energiewende monitoring process was only installed in fall of 2011 stipulating 2011 as the first reporting year (BMWi, 2012a). If this radical decision was able to give an impulse to innovation activities, it would be another justification for this course of action.

Third, there is a dispute to what extent Energiewende policies have *triggered changes within incumbent firms*. Given the lack of firm-level investigations elaborated as a research gap above, there is little understanding of what happened inside firms affected by Energiewende policies regarding their innovation decisions; how they perceived political intervention and when, to what extent and why they changed their innovation activities. The little that is known concerns the strategies and actions of large, incumbent electricity suppliers. In this literature there are two largely opposing explanations for their behaviors, one camp blaming the late reaction to the ongoing energy transition to corporate inertia (Bontrup & Marquardt, 2015), another one holding that it constituted deliberate actions to prevent systemic change (Kungl, 2015). This dispute has repercussions that go beyond electricity suppliers. Electricity suppliers only constitute one group of corporate actors relevant to innovation in the energy system. Others are, for example, the grid operators on local and national level (DSOs and TSOs, respectively) who have the critical task to build and maintain a grid network that can integrate fluctuating RES-E and provide for security of supply at the same time. Equally important are technology providers, who develop and supply the technological equipment needed in the energy system. This pertains to generation technology, but also physical and virtual grid infrastructure and technology directed at the demand side. Lastly, there are also materials firms, which have an important role to play regarding the development and supply of materials to achieve Energiewende targets, especially when it comes to physical grid technology and energy efficiency. In addition, many technology providers and materials firms are heavy consumers of energy at the same time, and therefore hugely affected on the process and operational side of their business, in addition to products. For all these corporate actors, gaining insights into the roots of firm decisions and if action (or inaction) regarding innovation are deliberate decisions or corporate inertia is important for the corporate decision-makers themselves and equally for policy makers alike. While policy objectives are usually set at a meso or macro level, i.e. for an industry or in an economy, respectively, the micro level, i.e. the choices of individual actors is what in the end cumulates in higher level results. Being able to interpret inaction as deliberate choice or inertia hence informs the appropriate political response. The same is true for corporate decision-makers in during a transition process. They too benefit from understanding organizational barriers to innovative activities in order to be able to better address them.

With respect to the current state of the literature, this thesis aims to contribute towards closing the research gaps and clarifying the controversies around the innovation effect of Energiewende. The empirical investigation that follows in chapter 6 addresses the three research gaps. The discussion in chapter 7 revisits the three controversies reflecting on the results of the empirical investigation.

5 Conceptual framework for empirical enquiry

This chapter prepares the empirical investigation by drafting the conceptual framework on which it will be based. The purpose of drafting a conceptual framework is to position this research within the academic literature outlined in chapter 2.2 and to clarify the approach towards empirical investigation in the following chapters. It has been stated above (section 2.2) that three literature streams – sustainability transitions research, environmental economics, and organization and management studies – are relevant to the research question. The development of a theoretical framework for empirical enquiry hence draws on these three literature streams. Since Energiewende constitutes a *transition towards sustainability*, the thesis is placed in the tradition of sustainability transitions research, more specifically the multi-level perspective (MLP). Since this sustainability transition is *politically-induced*, the research framework is also informed by environmental economics where ample research on the effectiveness of environmental policy has been carried out. Since the research interest lies in investigating *corporate innovation*, concepts from the organization and management literature will also be considered.

Developing an integrated conceptual framework from the combination of these three literatures is a novel approach to studying the innovation effect of the German energy transition and one of the key contributions of this thesis. The multi-level perspective in sustainability transitions research has not in this way been combined with environmental economics and organization and management studies yet. The combination of theoretical perspectives to investigate a specific research interest has the potential to further enhance the current understanding of the phenomenon under study. The integration of different theoretical angles to investigate one particular subject often shows that literatures are mutually beneficial and enhancing rather than exclusive. Researchers have called for integrated conceptual frameworks in the realm of the investigation of sustainability transitions before (Del Río González, 2009). As the review of the current state of research (cf. chapter 4) shows, existing investigations of this research subject tend to stand in only one of these theoretical literatures and hence disregard the potentially beneficial insights from other schools of thought. The integrated framework here constitutes a contribution to the theoretical literature as well as (through its findings) to existing knowledge regarding the research interest.

The framework presented here retains an open and flexible character as the research interest is exploratory and hence the research framework should not limit possible findings in advance (Eisenhardt, 1989; Flick, 2014, p. 65 ff). The framework constitutes backdrop and guidance for the empirical investigation, but does not make explicit hypotheses to be tested and confirmed. Instead, the theoretical framework scopes and structures the data collection and data analysis and provides an anchor to relate research findings to the existing theoretical and empirical literature.

The first section of this chapter explains why this thesis stands in the tradition of sustainability transitions research and fundamentally adopts a multi-level perspective (section 5.1). This clarification is necessary, since research in the tradition of the MLP typically uses its three levels as the conceptual framework, and the socio-technical system as unit of analysis, and the approach taken in this thesis differs significantly with the theoretical framework as set out in this chapter and the focus on companies as actors within a system, rather than the system as such. Furthermore, albeit this is increasingly changing, the MLP is typically associated with the study of past transitions and it needs to be clarified how the approach can be used to study transitions that are still ongoing, as is the case with *Energiewende*. The second section of this chapter (section 5.2) develops the conceptual framework for the case studies that follow in chapter 6 and explains the four elements of the framework innovation activities (section 5.2.1), German Energiewende policy mix (section 5.2.2), context factors (section 5.2.3) and firm characteristics (section 5.2.4). The final section elaborates characteristics of the firms in the energy technology value chain as they constitute the target population for the empirical research (section 5.3).

5.1 The multi-level perspective, ongoing sustainability transitions and corporate innovation

Sustainability transitions literature in general and the multi-level perspective (MLP) in particular are very suitable for studying the innovation impact of Energiewende. Energiewende is an ongoing transition towards sustainability that has at its core a transition of the socio-technical system for energy (esp. electricity) provision and usage in Germany, as explained previously (cf. section chapter 3.2). A couple of the basic tenets of the MLP, conceptually as well as ontologically, are highly suitable to this research interest. In other areas such as addressing ongoing transitions, investigating the effect of a policy mix, and studying corporate innovation the MLP needs to be qualified or expanded in order to make it applicable. Table 7 gives on overview of the assumptions similar to the MLP as well as departures from the structural MLP model. They are further detailed below.

Table 7: Assumptions in line with the MLP and departures from it in this thesis

Assumptions in line with the multi-level perspective:

1. Transition processes are co-evolutionary.
2. The three level interaction of the MLP is a useful heuristic to understand transitions.
3. Structure and agency are both important in transitions.

Departures from the structure of the multi-level perspective:

1. Since the German Energiewende is an ongoing transition, focus is on micro level dynamics and the activities of actors.
2. Since the research interest is the effect of a political course of action, the effect of a policy mix on innovation is investigated instead of niche developments.
3. Since the research interest is corporate innovation, firms are used as units of analysis and deliberately not classified as regime or niche actors.

First of all, although this thesis investigates the effect of Energiewende on corporate innovation, it fundamentally takes the perspective that transition processes are co-evolutionary and that therefore an innovation effect does not mean simple and linear causality. When policy makers set targets or develop new policies such as Energiewende they do so in reaction to societal developments that have previously taken place and with a certain vision and picture of the future in mind. These political actions then influence the behavior of social groups, individuals and companies, which in turn shapes the next round of political activities. In addition, decisions taken by these actors are always influenced by a multitude of factors, rather than a single one. These complex, iterative, and interdependent interactions take place continuously over a significant period of time, which makes it very hard to discern what exactly has caused what. Employing the MLP means to acknowledge this complexity and inherent interrelatedness and conceive any phenomenon as the unique result of the interplay of a set of influencing factors. Hence while investigating how and why innovation occurs there is no claim to causality in a sense that it can be replicated in a different context (cf. also the methodological discussion in section 6.1). The aim is to identify and understand a range of interrelated influencing factors and mechanisms in a context- and actor-specific setting, and deduce stylized facts and implications (Kaldor, 1961) that help policy makers and firms advance Energiewende.

Second, this thesis embraces the heuristic of the three levels that interact in a transition process. Distinguishing a landscape, regime and niche level to conceptualize "overall dynamic patterns in socio-technical transitions" (Geels, 2011, p. 26) makes sense intuitively. The definition of regime as path-dependent "deep structure" (Geels, 2011, p. 31) of a socio-technical system draws on well-established concepts from sociology, evolutionary and institutional economics (Dosi, 1982; Nelson & Winter, 1982; North, 1990). The two derived levels of niche and landscape explain sources of deviation as well as stability for the regime. In general, this provides a useful analytical framework for looking at and interpreting complex transitions.

Third, this thesis supports the views on the duality of structure and agency proposed by researchers in the MLP tradition. As explained above (section 2.2.1.4), because of the popularity of the three level model, it is frequently alleged that the MLP puts overemphasis on structure at the expense agency in the analysis and explanation of transition processes (cf. section 2.2.1.4). However, the importance of actors is stressed in key theoretical contributions to the development of the MLP (Geels, 2002, 2004, 2011; Geels & Schot, 2007). Agency and structure are mutually enabling rather than mutually exclusive analytical dimensions. The metaphor of the three levels is a useful and accessible representation of structure that should, however, not be taken as a justification to ignore agency (Geels, 2011). In contrast, agency is one of several analytical dimensions that one might take (Geels, 2004).

Despite this endorsement of the MLP in general, several things need to be clarified and adjustments made in order to make the MLP relevant to the research interest in this thesis (cf. Table 7). First, since Energiewende is still ongoing, it needs to be elaborated how the MLP can be used and what its contribution is to studying a socio-technical transition that is not yet completed. The heuristic of the three levels is especially suited to historical *ex-post* studies of transitions since the emergence of niches, the significance of landscape events, the evolution of technological trajectories and transition patterns, and the timing of regime shifts can conclusively only by understood in retrospect (Augenstein, 2015). Furthermore, the MLP is an interpretive framework, not a model to predict the future. This potentially limits its allure when it comes to studying transitions that are still ongoing, as one contribution of *ex-ante* studies is the ability to anticipate the future course of development. However, an increasing number of publications employ versions of the MLP to study ongoing transitions. They show that this perspective has its merits also when investigating contemporary phenomena (Augenstein, 2015; Geels, 2012; Kern, 2012; Van der Vleuten & Högselius, 2012).

First, building on the above contributions, the focus of this thesis is dynamics on a micro level and the activities of actors in the transition process. Niche-regime dynamics (Augenstein, 2015; Geels, 2012), landscape-regime dynamics (Geels, 2012; Van der Vleuten & Högselius, 2012), regime-internal dynamics (Geels, 2012; Van der Vleuten & Högselius, 2012) and multi-regime dynamics (Augenstein, 2015) are important to understand ongoing transitions as change starts on these very low levels before it spreads and manifests itself in a regime shift and ultimately the transition of a socio-technical system. Since it is actors that are shaping structural change, a focus on the cognition, strategies and behaviors of actors is worthwhile especially in ongoing transitions (Augenstein, 2015, p. 87). In a niche, actors work on radical innovations and seek to establish them, possibly changing the socio-technical regime as a result. In a regime, actors react to niche, regime-internal and landscape developments in a way that may maintain and reinforce the regime, but may due to regime-internal semi-coherence also cause tensions and bring about regime cracks (Geels, 2012, p. 472 ff). Even landscape developments only gain significance because of the way they are interpreted and acted upon. Landscape developments may be perceived in a way that reinforces established cognition and behaviors and hence maintains the current regime, or in a way that challenges these. Seen in isolation, a landscape development does not imply a definite route for action. Augenstein (2015) illustrates this point using the Fukushima nuclear incident as an example: "Even though it [Fukushima] is used as legitimization for a government-induced energy transition project focused on renewable energies, it could in theory have just as well been used as an argument for increased efforts in nuclear R&D or a political focus on technologies improving safety and reducing risks" (Augenstein, 2015, p. 85).

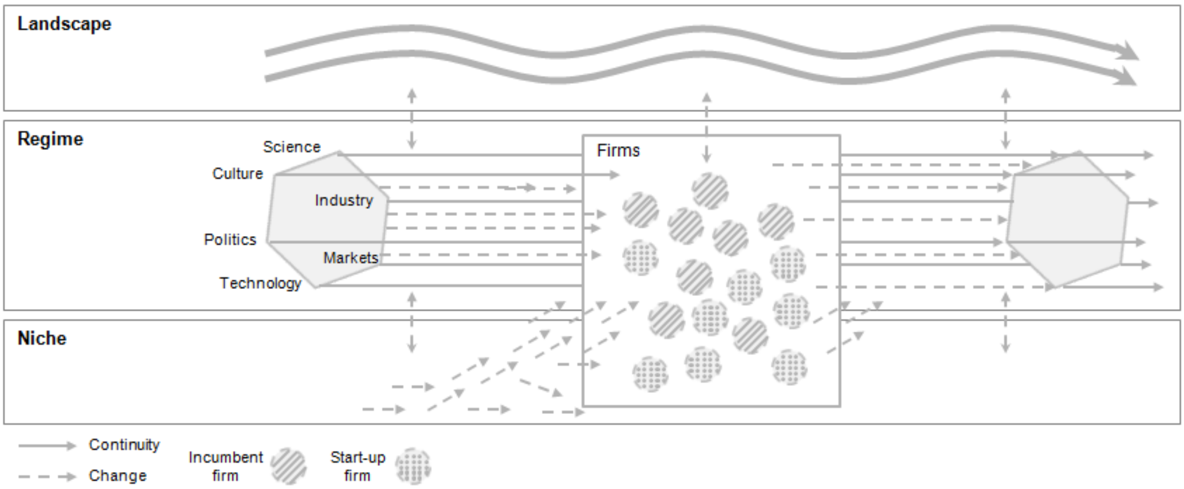
While this approach of analyzing ongoing transitions in terms of the MLP does still not enable a clear and unambiguous prediction of the future, it does, however, help to collect indications and identify trends from which one may deduce the future development. Focusing on actors one can hence infer what changes are emerging and may manifest on a systemic level over time. For example, the identification of mechanisms and patterns in current transitions, which have previously also been observed in historic transitions, may provide insights into the rate and direction that a transition will take on (Augenstein, 2015; Geels, 2012). In this way the MLP can even be useful to assess the effectiveness of policies in stimulating transitions (Kern, 2012). Furthermore, in the case of an ongoing transition lessons learnt from the study of actors may if dispersed still influence transition dynamics. The results can inform actors in the current transition and influence their decision-making, which will in turn shape how the transition plays out in the future. This corresponds to the objective of this thesis to draw implications for policy makers and firms. Instead of being universally valid in all cases irrespective of context, this can hence be relevant in the particular case of the German Energiewende.

Second, the framing of Energiewende as a politically-induced transition and the research interest in investigating the effect of the politics of this transition on corporate innovation means this thesis looks at a political course of action as the primary source of change. It has been noted before (section 2.2.1.4) that research using the MLP can have a bottom-up bias in the sense that niches are usually seen as the source of innovations. However, an improved understanding of the role of politics and policies in sustainability transition processes has already been called for (Markard et al., 2012). This thesis explicitly departs from technological niches here, to focus on the effect of public policy instead. That does of course not mean that niches are not important. First, transitions on all levels co-evolve, as explained above. Second, public policy that implements Energiewende would most likely not have emerged in its current form had it not been for technological "niche" developments of renewable energy generation technology and civil society organizations demanding their use, as described in chapter 2.3.

The effect of public policy on an ongoing transition has been analyzed using the MLP before (Geels, 2012; Kern, 2012; Kern & Smith, 2008). The MLP cannot provide the (quantitative) effectiveness assessments of public policy that are common in the environmental economics literature, but instead sheds light on the potential of a policy to stimulate transitions. Geels (2012) argues that public policy needs to pursue two objectives in order to foster sustainability transitions: first, it should stimulate the development of niche innovations and second, it should exercise pressure on the regime to adopt such innovations through economic, market-based instruments as well as traditional environmental regulation (Geels, 2012, p. 9). The MLP can help evaluate to what extent and how a policy contributes to transition dynamics and prompts structural change while of course "always keeping in mind that the eventual outcome with regard to an overall transition of a socio-technical system as a whole depends on a plethora of other factors as well" (Augenstein, 2015, p. 110). Because of the complexity involved in a transition it is again not possible to predict the exact outcome of a policy, but it is possible to get a better understanding of what might happen and what factors may prove to be important.

Third, since the research interest of this thesis is corporate innovation, it is not the energy system as such, but companies as actors within it that are the units of analysis. This is rather unusual, most MLP contributions tend to study systems and therein the emergence of niche innovations, which usually involves the focus on structural elements and groups of actors, if actors are involved at all. In contrast to this, this thesis explicitly studies firms individually. The firms that this thesis is interested in can, however, all be considered to be part of the same socio-technical system, that is the system around the supply of and demand for electricity including the technology required for this, or as it is called here, the *energy technology value chain* (cf. section 5.3). Moreover, firms (or other actors, for that matter) are deliberately not assigned to the levels niche or regime, or to specific regimes, but they may represent either or both (cf. Figure 12). The approach here hence constitutes an extension of the MLP literature in that respect.

Figure 12: Firms within a multi-level perspective of socio-technical change



Source: Adapted from Geels, 2004

The reason for not distinguishing niche and regime actors, at least not ex ante, is first, that this affiliation may change and second, that one organization may combine aspects of both, regime and niche. Studies especially of ongoing transitions show that the boundaries between niche and regime, as well as between fading and emerging regimes, are blurry and fluctuate over time (de Haan & Rotmans, 2011; Geels, 2004). Degrees of tension between niche and regime vary from antagonistic to symbiotic (Geels, 2011). As a consequence the delineation of niche and regime actors is not clear, neither in terms of actors nor in terms of structure (Augenstein, 2015, p. 85). Assigning categories beforehand can even limit the outcomes of empirical research as characteristics associated with the respective levels may leverage research biases and predefine results. Furthermore, organizational actors can stretch over both levels and be both at the same time, a regime actor and a niche actor. The organization and management literature calls this the tension between *exploitation* (of existing knowledge and routines) and *exploration* (for new knowledge and radical innovations) (March, 1991). Organizations that master the art of both simultaneously are often termed *ambidextrous* (Tushman & O'Reilly, 1996). However, it can be expected that incumbent actors lean towards an established or fading regime, while new players lean towards niches and a new or emerging regime. Lastly, actors can be part of multiple systems and regimes at the same time. All of these hold for corporate and political actors alike. Even more so than firms, political actors are typically considered representatives of the established regime. However, research has demonstrated that novel political forces and the instituting political actors can also constitute a source of niche innovation (Jacobsson & Lauber, 2006; Lockwood, 2016; Sühlsen & Hisschemöller, 2014). Therefore the focus of the empirical research in this thesis is on actors, their cognition and their concrete actions set against the backdrop of insights from the multi-level perspective in sustainability transitions research.

5.2 Elements of the conceptual framework

As explained in the previous section, the multi-level perspective of sustainability transitions studies is used as an ontological and conceptual base, but a research framework that also integrates concepts from environmental economics and the organization and management literature is devised. Furthermore, the analytical perspective is changed from socio-technical systems to firms as units of analysis, albeit these firms are members of a particular socio-technical system, namely the socio-technical system for energy in Germany, as defined by the energy technology value chain (cf. section 5.3).

It has been argued before that the MLP could benefit from an integration of insights from literatures in business and strategic management. Geels (2011, p. 30 f) states that at least three theories could be well integrated into an MLP framework: first, the strategy literature on alliances and complementary assets (Rothaermel, 2001) could expand the understanding of niche-regime dynamics by investigating how incumbents and new entrants collaborate. Second, literature on organizational learning such as ambidexterity (O'Reilly & Tushman, 2008; Tushman & O'Reilly, 1996) and the quest of companies to exploit existing knowledge or explore new knowledge (March, 1991) could help study firm-internal transition processes. Moreover, with a research interest in the evaluation of political initiatives that can broadly be described as "pro-environment" it makes sense to also build on the learnings regarding the innovation effect of environmental policy provided by the vast literature body of environmental economics (cf. section 2.2.2).

The research framework presented in the following is deliberately open. Since the research interest is to explore, it can only be adequately pursued in a framework that leaves room for new insights and is not constrained by narrow definitions and a limited number of hypotheses (Eisenhardt, 1989; Geels, 2011). This is also in line with the ontological approach put forward by the multi-level perspective. Given the empirical complexity and inherent interrelatedness of socio-technical transitions a narrow framework would not be able to satisfy the research interest as it foregoes the ability to develop new knowledge. In the next chapter (chapter 6), the framework will be used as a basis for data collection in form of semi-structured qualitative interviews for the qualitative case studies that form the heart of the empirical research in this thesis.

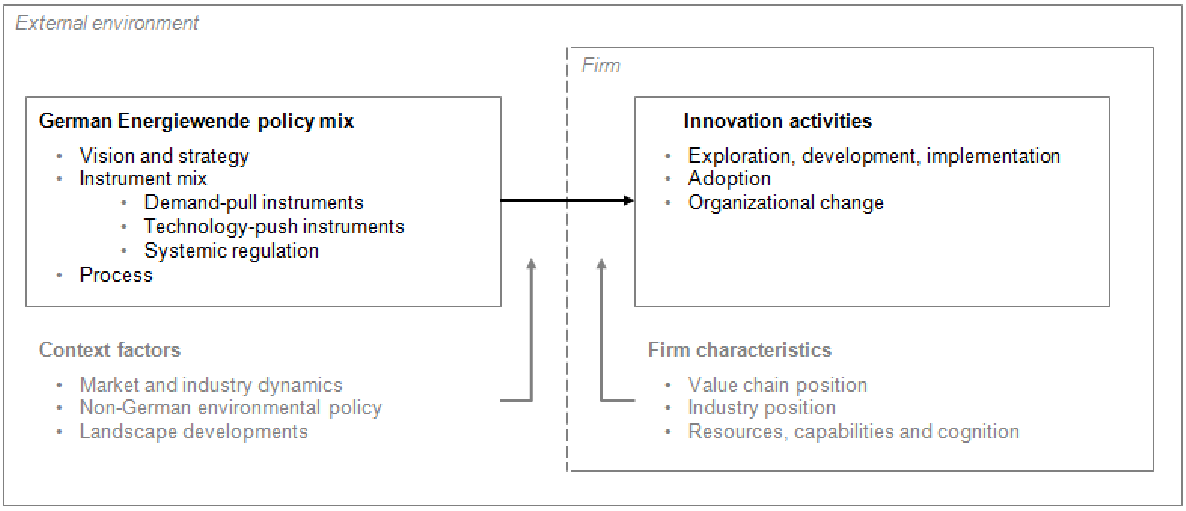
Three empirical research questions are hence asked, the combined answers to which will address the research objective to explore the effect of Energiewende on corporate innovation:

1. *How have German firms over time changed their innovation activities in the light of Energiewende?*
2. *What is the impact of the individual components of the Energiewende policy mix on these innovation dynamics?*
3. *What is the impact of confounding factors and how do they interact with the components of the Energiewende policy mix?*

To answer these empirical research questions, the conceptual framework is a simple representation of a relationship between firms and their external environment. Firms are embedded in a particular environment with which they interact because of permeable firm boundaries (Chesbrough, 2003; Kogut & Zander, 1996; Teece, 1986). Through these permeable boundaries they perceive developments in their environment and take them in to assess their relevance for corporate activities. Firms carry out innovation activities. The rate and direction of these innovation activities is the result of the interpretation of drivers from the external environment, as well as factors internal to the firm (Del Río González, 2009; Dosi, 1988). The link that is under particular investigation here is between the German Energiewende policy mix and corporate innovation activities. Confounding influences from context factors and firm characteristics will also be investigated.

Figure 13 gives a graphical overview of this research framework. The four elements will be further explained in the following sections. Comparable research frameworks have been drafted by other researchers studying research questions in the realm of sustainability, environmental policy and corporate innovation (Hoppmann et al., 2013; Rogge, Schleich, et al., 2011; Rogge, Schneider, et al., 2011; T. S. Schmidt et al., 2012).

Figure 13: Research framework for company case studies



5.2.1 Innovation activities

Earlier in this thesis (section 2.3) innovation has been defined as the intentional and targeted invention, implementation and diffusion of a subjectively new or improved product, process, strategy, organization or business model that is perceived to be relevant in the context of Energiewende. The theoretical framework builds on this definition and studies corporate innovation in terms of innovation activities.

Throughout the innovation process companies engage in several activities in an effort to achieve an innovation. Innovation activities are all scientific, technological, organizational, financial and commercial steps which actually lead to, or are intended to lead to, the implementation of innovations and therefore contribute towards corporate change. Some innovation activities are themselves innovative, others are not novel activities but are necessary for the implementation of innovations (OECD & Eurostat, 2005, para. 249). Innovation activities are an indicator of innovation inputs, rather than outputs. Studying innovation in terms of input indicators makes sense for the research interest of this thesis since input indicators are closest to the actual process of innovation on firm level. As such, they are suitable to track changes in innovation behavior, e.g., as response to external triggers, with minimal time lag, and also capture the intention to innovate (Arbussa & Coenders, 2007).

Not all corporate innovation activities are likely to be relevant to the transition of the German energy system. Especially large, diversified firms and firms on the upstream side of the value chain (i.e. energy technology and materials) will innovate in areas that are unrelated to the research interest. Only innovation activities "relevant in the context of Energiewende" are supposed to be investigated. The definition of relevance thereby will be left to the case study participants themselves as this may vary across firms.

Innovation activities can vary regarding direction they take and the rate, or intensity, with which they are pursued (Arrow, 1962a; Rogge, Schneider, et al., 2011). A special interest is taken in investigating when and why innovation activities take a certain direction and when and why the intensity of these activities changes. The resulting picture of cumulated changes in innovation activities of the energy technology value chain over time suggests the dynamics of innovation taking place and forces that contribute towards developing and changing the German energy system.

In this thesis innovation activities are clustered into three different categories: exploration, development and implementation, adoption, and organizational change. This corresponds to the Schumpeterian process of innovation (cf. section 2.1.1) and covers it in full from invention to diffusion. It hence addresses the research gap of a too narrow definition of innovation (cf. section 4.3). Exploration, development and implementation are activities at the beginning, or upstream part, of the innovation process, what Schumpeter refers to as invention and innovation. Adoption is an activity at the end, or downstream part, of the innovation process as it contributes to diffusion. Exploration, development, and implementation, as well as adoption are mainly connected to product and process innovations and are mostly, but not always, technological. Organizational change cuts across the Schumpeterian innovation process that is mainly connected to non-technological innovations. All activities subsumed under these categories are commonly investigated in innovation studies, which ensures a comparability of the results with the existing academic literature ((Hoppmann et al., 2013; Rogge, Schneider, et al., 2011; T. S. Schmidt et al., 2012).

Exploration, development and implementation

First, there are activities targeted at *exploration, development and implementation*. These are activities with the objective to discover or develop something new for the firm and implement it consequently. While invention and innovation are distinct steps in the Schumpeterian model of innovation (cf.

Figure 2), they are in practice often hard to separate. Firms usually engage in invention not for the sake of the activity itself, but with the target to use its result. The objective to innovate is hence immanent in the decision to invent, which is why the activities are not looked at separately here.

Within exploration, development and implementation, one can distinguish between research and development (R&D) and other activities. Research and development is the most prominent innovation activity and widely employed as an indicator in quantitative as well as qualitative studies (OECD & Eurostat, 2005; Schmiedeberg, 2008). It is often broken down into various types of R&D where standalone inhouse R&D is distinguished from R&D contracted out to external parties and R&D expenditure incurred in cooperative projects with other entities (OECD & Eurostat, 2005; Schmiedeberg, 2008). While a second "D" for "demonstration" is also sometimes added to explicitly include all expenditure incurred before the implementation of a product or process, this thesis sticks to the more frequent use R&D. Data availability permitting, R&D is a good indicator for the effort that goes into technological product and process innovations (OECD & Eurostat, 2005). Since it is quantifiable e.g., per company per year or per technology, it provides many options for data analysis. In fact, many innovation surveys mainly focus on gathering R&D data over time.

R&D, however, is only one of several exploration, development and implementation activities at the firm level. First, technological developments may take place outside of "classical" R&D departments, e.g., in production facilities or project-specific setups (Evangelista, Sandven, Sirilli, & Smith, 1998; Kline & Rosenberg, 1986). Second, non-technological invention and implementation is an ever more important area that is typically not accounted for in R&D (OECD & Eurostat, 2005; Arbussa & Coenders, 2007). Activities for non-technological invention and implementation are seldomly further classified. Very generically they may involve idea generation, concept development, testing and implementation in a wide variety of areas such as new business development, non-physical products i.e. services, marketing and customer experience, or business model.

In the context of Energiewende exploration, development and implementation activities with the objective to re-invent larger parts of corporate activities may be expected. As a sustainability transition like Energiewende places an emphasis on environmentally-friendly technology more interest in such technology can be expected. Indeed current research has already shown the rise of companies producing renewable electricity generation technologies and other environment-friendly technology has increased in Germany (Laleman

& Albrecht, 2014; J. I. Lewis & Wiser, 2007; Pegels & Lütkenhorst, 2014). Changes may hence include an expansion of the range of activities a firm engages in (e.g., new products or business areas) in the form of explicit diversification of the range of corporate activities or replacement of old activities by new activities.

Adoption

Second, innovation activities include the *adoption* of novelties. These are activities where physical and non-physical assets produced outside of the firm are adopted and subsequently employed without making significant changes to the asset. These activities include the acquisition of external knowledge such as licenses, patents or trademarks as well as acquisition of machinery and equipment (Arbussa & Coenders, 2007; OECD & Eurostat, 2005). In addition, there are also activities that are harder to observe because they are not as formalized as outright expenditures. These may include the absorption of knowledge from the external environment for that knowledge to be exploited internally, thereby contributing for the knowledge to spread (Arbussa & Coenders, 2007). In the context of Energiewende it is important to pay special attention to adoption as many contributions that negate an effect of Energiewende on innovation do so by limiting their attention to the earlier stages of the innovation process and ignoring diffusion (cf. section 4.3).

Organizational change

Third, there are innovation activities targeted at the firm itself, more precisely its internal organization. *Organizational change* is increasingly recognized as a crucial type of a firm level innovation activity (Christensen & Rosenbloom, 1995; OECD & Eurostat, 2005). Such activities can contribute to and help implement technological changes, but also occur independently. As activities take place within the firm, they are usually not formally tracked and often not reported to the outside world, which makes them very hard to measure. Furthermore, activities at the organizational level are much broader than the previous two innovation activities explained and do not lend themselves to a classification. Activities may include the development and implementation of a strategy and objectives as well as various organizational changes regarding structure, processes, people and capabilities, or interaction with the external environment.

Organizational change is expected to be of particular importance in the context of a sustainability transition like Energiewende. A significant change in the dynamics of a firm's external environment can be expected to affect the strategic priorities for innovation as well as the way that innovation activities are organized. Especially very new innovation that constitutes a break with previous corporate strategy, processes and routines, or business logic may require a somewhat separate organizational structure in order to develop and grow (Christensen & Rosenbloom, 1995; C. W. Hill & Rothaermel, 2003). This idea is very similar to the conception of niches in the sense of the multi-level perspective (Geels, 2011), just that the niche here is contained in one corporate organization. Also, firms may experiment with organizational structures that allow them to explore new developments while at the same time also staying strong in the areas they are already good at i.e. create an organization that is more ambidextrous (O'Reilly & Tushman, 2013).

Related to this is also the notion of changing the entire business model. As explained earlier (cf. section 2.2.3), the business model is a multi-dimensional, comprehensive concept that describes how a company creates and captures value through its specific combination of target market, value proposition, value chain, cost and profit, value network and competitive strategy (Chesbrough & Rosenbloom, 2002). Changes to the business model may be required where the company finds that its way of doing business is in many aspects no longer suitable to a new external environment. This may especially be the case in periods of rapid and radical external change (Chesbrough, 2007; Tongur & Engwall, 2014), but also the proposition to build a new business model based on sustainability has been developed (Schaltegger, Lüdeke-Freund, & Hansen, 2012).

Building on the sustainability transitions as well as the organization and management literature, one can also expect an effect on the way that a firm organizes its collaborative activities with firms and other external partners. Collaboration can take place in the early steps (invention/innovation) of the innovation process and will here predominantly concern traditional innovation functions such as R&D, but it can also take place in the latter step of diffusion where it may take the form of marketing collaborations or joint ventures in a new business area. In the context of sustainability transitions, collaboration may be important for introducing new technologies or other innovations to a market. The ability of new entrants to cooperate with exiting players may be decisive for a niche technology to take off (Geels, 2011). For incumbent firms the collaboration may be a learning opportunity, a re-positioning in light of the expected success of the niche technology, or an extended due diligence if the objective is a possible acquisition (Grant & Baden-Fuller, 1995; Hagedoorn & Duysters, 2002; Powell, Koput, & Smith-Doerr, 1996). All collaborations are efforts to address the uncertainty and complexity that doing new things, especially under the pressure of external change, entails (Chesbrough, 2003). Complementarity of assets and resources between the incumbent and new entrant plays a key role here (Rothaermel, 2001; Tripsas, 1997). In addition to collaboration between incumbents and new entrants, collaboration may also take place vertically along the value chain with suppliers or buyers, with firms from other industries, or actors other than firms (Hagedoorn, 2002; Von Hippel, 1976, 1994). In fact, "open innovation" i.e. seems to be the new paradigm in management literature and practice (Chesbrough, 2003; Gassmann et al., 2010).

5.2.2 German Energiewende policy mix

In the external environment the Energiewende policy mix is explicitly separated from other influencing factors. This is because of the research interest in investigating the effect of the politics of Energiewende on corporate innovation. Of course the Energiewende policy mix can neither be seen in isolation, nor are its boundaries definitely clear. However, representing it here as a distinct influencing factor is a necessary and justifiable simplification for the following empirical research.

In line with the conceptual propositions by Rogge and Reichardt (2013) a comprehensive policy mix framework that is especially suited for investigating environmental technological change is employed. Three aspects of the policy mix are distinguished: vision and strategy, an instrument mix, and policy process. This distinction builds on theoretical contributions and empirical findings in, mainly, the environmental economics literature.

Vision and strategy encompasses policy objectives and targets, as well as roadmaps and principal plans for achieving them (Rogge & Reichardt, 2013, p. 8 f). This aspect hence captures the long term perspective inherent in a political course of action. Empirical research has shown that political vision and strategy is an important determinant of corporate innovation and therefore likely to play a role in the context of Energiewende. Although the political long term perspective does not tend to be relevant for day-to-day activities since it does not set actionable incentives, it provides guidance to the future possible state of the world and can hence steer firms' innovation activities, especially where they are geared towards the long run and involve high uncertainty (Rogge, Schneider, et al., 2011; T. S. Schmidt et al., 2012).

The *instrument mix* constitutes the implementation of the long term perspective in concrete policies. As explained earlier in this thesis (cf. section 2.2.2), empirical research in environmental economics has evolved in particular around investigating which type of policy instruments is best suitable to foster environmental innovation, what design features a policy needs to possess and how policy instruments need to be combined in an instrument mix to bring about innovation. To address the multitude of ways to look at policy instruments, Rogge and Reichardt suggest a useful matrix typology that distinguishes instruments by type (economic instruments, regulation, information) and purpose (technology-push, demand-pull, systemic regulation) (2013, p. 12). Adopting this typology will allow to link research findings back to the respective policy instrument debates found in the academic literature. For the sake of simplicity, this thesis classifies policy instruments primarily by their purpose in terms of innovation i.e. the latter one in the matrix set up by Rogge and Reichardt; technology-push instruments, demand-pull instruments, and systemic regulation (cf. section 2.1.3).

The last aspect, *process,* refers to the emergence and implementation of these policy elements rather than their content or design features as such. The policy-making process refers to the stages of the policy cycle from the identification of the need for political intervention over policy formulation and decision-making to implementation and assessment (Howlett, Ramesh, & Perl, 2009). Firms tend to monitor policy processes relevant to them and interact with policy makers throughout this process thereby influencing the outcome and being influenced in return. Firms may adjust their behavior before a certain policy is being implemented (or adjusted) based on their expectations formed throughout the policy-making process (Hillman, Keim, & Schuler, 2004). Especially since Energiewende politics is not fixed at one point in time, but has evolved and changed significantly over the years, the policy process can be expected to be important here. Specific steps or episodes in policy-making around Energiewende may have had an influence on innovation activities, but once again also the style of the policy-making process and its features in terms of e.g., predictability and reliability (Rogge & Reichardt, 2013).

5.2.3 Context factors

In addition to the German Energiewende policy mix, several other factors of a firm's external environment can be expected to affect innovation activities. It should be noted here again that the notion of co-evolution implies that these context factors are interrelated with one another and also with the German Energiewende policy mix that is at the core of the research interest.

Representing them as separate factors is hence a simplification. Four context factors are taken into account here: market and industry dynamics, non-German environmental policy, technological developments and landscape developments.

First, environmental economics and management and organization studies stress that *market and industry dynamics* such as supply and demand, prices, competition and new entry may affect innovation decisions (Ahuja, Lampert, & Tandon, 2008; Jaffe et al., 2005; Newell, Jaffe, & Stavins, 1998, 2006). In the case of Energiewende several factors such as e.g., demand for environmentally-friendly technology, the electricity price or intra-industry competition could be important. A difficulty here is that market and industry dynamics can be an influencing factor in their own right, but they can also be a mechanism through which environmental policy plays out in a dynamic way, e.g., when demand-pull policies create markets for a specific application (Hoppmann et al., 2013; Requate, 2005). This distinction needs to be paid attention to in the analysis.

Second, policies other than the one under investigation, i.e. *non-German environmental policy*, may affect corporate innovation activities. Since the study is situated in the realm of environmental policy, a policy area that is also regulated on a European and international level, policies at these levels may have an impact. Indeed several empirical studies suggest such a link e.g., between the European emissions trading scheme and innovation activities of firms (Cames, 2010; Martin et al., 2011; Rogge, Schleich, et al., 2011; Rogge, Schneider, et al., 2011; T. S. Schmidt et al., 2012).

Third, *landscape developments* may also have an impact. The multi-level perspective holds that exogenous events may disrupt established regime structures and cause regimes and systems to change (Geels & Schot, 2007). In the context of Energiewende, nuclear incidents such as the one at Fukushima in 2011 or Chernobyl in 1986 may have constituted such events (Jacobsson & Lauber, 2006; Strunz, 2014). Furthermore landscape developments attenuate change on the regime level (Geels & Schot, 2007). In the management literature as well as in company practice landscape developments are often phrased in terms of megatrends. Megatrends are slowly evolving, long-term changes that affect a wide range of aspects of society and economics on a global scale (Naisbit, 1982; Slaughter, 1993a). Frequently cited megatrends today include changes to global demographics (Miles, 1999), income structures (Kharas, 2010), the digitalization of all aspects of life (Hood & Margetts, 2007; Rosenberg, 2001; Tapscott, 1996) and global warming and climate change (N. H. Stern, 2006).

5.2.4 Firm characteristics

Lastly also firm characteristics can influence corporate innovation activities (Ahuja et al., 2008). Four firm characteristics are distinguished here: value chain position, industry position, resources and capabilities, and cognition.

First, the *value chain position* within the energy technology value chain can be expected to be of importance (Rogge, Schneider, et al., 2011; T. S. Schmidt et al., 2012; Taylor, 2008). The energy technology value chain is made up of different types of corporate actors, two of which are distinguished here. Energy technology and materials companies provide the technology that is used to generate electricity and transport it. Electricity generation and transmission firms generate the electricity and deliver and sell it to customers. Each of the value chain steps is defined rather broad and encompasses various industrial sectors. The two value chain steps differ in the nature of their business, the structure and dynamics of the market and industry they operate in, and the role that innovation has played traditionally (see also section 5.3).

Second, a firm's *industry position* i.e. whether a firm is long-established in an industry or a new entrant may affect innovation activities. Industry incumbents are typically associated with inertia and resistance to change, while start-ups are considered dynamic, entrepreneurial and quick to adapt. There is a bias in innovation studies to focus on incumbents with ample empirical research on incumbent performance in the light of radical technological change (C. W. Hill & Rothaermel, 2003). Start-ups are usually only investigated in the context of entrepreneurship (Baumol, 2004) and as the source of technological change. However, as Energiewende has arguably helped bring about entirely new industries like wind or solar and helped many companies in these industries grow (J. I. Lewis & Wiser, 2007) it is worthwhile making this distinction and paying attention to the differential effect in terms of industry position here.

Third, the resources, capabilities and cognition that a firm possesses may also influence innovation activities. The resource-based view of the firm holds that firms are heterogeneous actors characterized by their resources and capabilities (Barney, 1991) and that differences in firm characteristics are likely to lead to variations in innovation activities as well as interpretations of external events (Dosi & Nelson, 2010; Tripsas & Gavetti, 2000). Clearly it is difficult to identify resources and capabilities from the outset. The technology portfolio might provide a clue as it represents a firm's technological capabilities and assets (Christensen & Rosenbloom, 1995) and consequently determines the degree to which it is affected by Energiewende. This can play out in various ways. On the one hand being strongly invested in particular assets and the customer and value network relationships that come with it can impede change (Christensen & Bower, 1996), on the other hand a large stock of knowledge generally boosts the capacity to absorb further learnings from the environment (Cohen & Levinthal, 1990). Moreover, the degree of technological diversification as such may play a role. In general is positively associated with innovation activity as companies are considered to be more open to explore (Chen, 1996) and knowledge can be transferred across different technological domains (D. J. Miller, Fern, & Cardinal, 2007). But one could also imagine that diversification decreases the incentive invest in innovation when a certain technology that is threatened by an external environmental change can easily be abandoned. Cognition may influence the interpretation of external events and therefore the reaction to them in terms of innovation activities. The importance of cognition is recognized across various literatures. Companies operate with a dominant logic of heuristic rules, norms and beliefs that guides decision-making (Prahalad & Bettis, 1986). Corporate cognition helps companies make sense of their external environment and influences corporate decisions regarding strategy and innovation (Barr, 1998; Kaplan & Tripsas, 2008; Nooteboom, 2005) (cf. section 2.2.3). It is not the change in the external environment itself, but rather the corporate interpretation of that change that determines the response (Barr, 1998; Dutton & Jackson, 1987; Kaplan & Tripsas, 2008). For example, whether a change in the environment is perceived as an opportunity or a threat can significantly influence corporate reaction (Dutton & Jackson, 1987; Sharma, 2000). Cognition is also what determines if a political course of action or policy is deemed to be credible, stringent, or predictable (cf. section 5.2.1). Expectations of the future are also formed based on cognition and are equally important for corporate actions (Requate, 2005). However, the dominant logic of a firm can also render it unable to respond to external developments (Tripsas & Gavetti, 2000) and can impede making necessary changes to the business model (Chesbrough & Rosenbloom, 2002). In the language of the multi-level perspective, corporate cognition reflects the rules of the regime that a firm is embedded in. Developments on the landscape or niche level only gain relevance when they are interpreted by regime actors and hence in light of these rules (Augenstein, 2015, p. 85). But just as regimes are made up of various sub-regimes and their rule sets are only semi-coherent, corporate cognition can be expected to vary across firms and change over time. As a transition is defined as regime change (Geels, 2011, p. 26), a change to the cognitive structure of regime actors determines the success of a transition. In the context of the influence of Energiewende on corporate innovation one can hence expect cognition to be of pivotal importance.

5.3 The German energy technology value chain

Firms of the energy technology value chain constitute the population of which cases will be selected in the empirical part (chapter 6). The energy technology value chain was chosen as the research case, because it is these firms that are particularly strongly affected by the transition of the German energy system and from which innovation as a response to the transition, but also innovation that will further shape the transition, is expected. The German energy technology value chain is defined as the group of corporate actors in Germany that help fulfill the function of the energy system, i.e. to provide and utilize energy. While there may be several possibilities to cluster these actors into different sectors and industries, they are distinguished by two different functions here: first, electricity generation and transmission on the downstream end of the value chain and second, provision of energy technology and materials at the upstream end. It is hence vertical steps that are differentiated, although the linkages between both types of firms may indeed be circular as both are potential suppliers and customers of one another; firms of the second group may supply physical, technological products to firms of the first group, while firms of the first group may supply electricity.

The two groups exhibit fundamental differences in terms of their business, their industry, and the role that innovation traditionally plays (cf. Figure 14). These differences are likely to have an impact on their reaction to Energiewende in terms of innovation activities, which is why value chain position has been included in the conceptual framework as a confounding factor (cf. section 5.2.4).

Figure 14: Comparison of energy technology value chain steps

		Electricity generation and transmission	Energy technology and materials
Business	Core activities	Generation, transmission and distribution of electricity Provision of heat and gas	Development and manufacturing of physical goods
	Range of products (diversification)	Low: focus on electricity	Usually high: often various types and applications
	Nature of product	Service	Goods (main) and services
Industry and market	Industrial sectors	Electricity generation Electricity transmission Electricity marketing and trading	Electrical & mechanical engineering Chemical industry Others
	Geographic reach	National (mainly)	International
	Industry structure	Concentrated: four dominant firms in Germany	Dispersed: several large, many small firms globally
	Intensity of regulation	High: legacy of state-owned natural monopolies, regulation of all aspects of corporate activity	Low: subject to standard corporate regulation
	Profitability	High: historically >10% EBIT margins	Low: historically <10% EBIT margins
	Examples of key players in Germany	RWE, E.ON, Vattenfall, EnBW	Siemens, Bosch, BASF, Linde
Innovation	R&D intensity	Low: typically <1% of revenues	High: typically >3% of revenues
	Focus of technological innovation process	Diffusion (adoption of technology)	Invention, implementation (development and commercialisation of technology)

Electricity generation and transmission firms are the classical utilities that operate large power plants, generate electricity and transport and distribute it to industrial, commercial and private customers. In addition to electricity they are often active in the production and distribution of heat and gas as well. While they increasingly offer services and heat and gas are striving adjacent business areas for many firms, their core product, the provision of electricity, has remained virtually un-changed since the development of on-grid electricity in the 19th century (Cames, 2010). The product is actually a service as electricity is not provided as a physical good that can be stored, but consumed immediately as it is just a source of energy. Being defined by physical laws its properties and as such product characteristics cannot easily be differentiated. Moreover, the provision electricity (but also heat and gas) relies on heavy physical infrastructure, networks of transmission and distribution grids, which transport energy from points of production to points of use. The network feature of the industry implies rising returns to scale and therefore a natural tendency towards monopoly. Combined with a high public interest in energy security, this has rendered the industry traditionally highly regulated. Regulatory involvement includes subsidies and guarantees for generation facilities, strict rules for electricity markets and grid access, and close scrutiny of industry conduct and price setting behavior. In the past even more intrusive regulation such as restrictions of competition, geographical monopolies and price targets were the norm in the industry. Indeed the industry only emerged from state-owned, protected utilities to competitive firms following the liberalization and privatization efforts of the 1990s (cf. section 3.3.3). Yet, energy generation remains an industry where regulation is key and business often comes second. However, profitability has usually been high with energy companies routinely enjoying operating margins beyond 10%. As a consequence of a stable core product, large sunk costs for physical assets and the attenuating lines of stable regulation, industry dynamics have traditionally been low. While the liberalization of the electricity market and the abolishment of territorial monopolies opened doors for new players, the industry quickly consolidated with four large firms continuing to dominate the supply of electricity in Germany.

Electricity generation and transmission has traditionally been regarded a low-innovation industry. In two of the most important quantitative indicators of innovation, R&D expenditures and capital investments, the industry ranks among the lowest in Germany (Rammer et al., 2014). Being a services industry, one must of course be cautious when applying such traditional criteria of innovation as they exhibit a bias towards manufacturing firms; for example services industries seldom report R&D (OECD & Eurostat, 2005). However, there is no industry-level dynamic that indicates overhauls in the sense of creative destruction and the energy industry has not been known for innovations of any kind.

Energy technology and materials firms are companies of various industries that develop, produce and sell products for the supply and utilization of energy. Such firms may be found in several industrial sectors including electrical engineering, mechanical engineering, software and information technology and process industries. Irrespective of formal sector affiliation all companies that offer products and services relevant to the energy system qualify here. In the context of Energiewende, especially products for energy generation, storage, transmission and distribution, energy management and the efficient utilization of energy are sought after. In addition to the technology as such, materials and services for these areas of application are of equal importance (Löschel et al., 2014c, p. Z-21). Energy technology and materials firms, especially the larger ones, tend to be diversified and offer a large range of products for various applications. However, smaller, focused firms exist as well. Since manufacturing is a stronghold in Germany, products tend to be physical, but the provision of services is gaining importance. In contrast to electricity, heat and gas, product differentiation through e.g., technological properties is possible and a standard term of competition. Due to the industrial base, electricity is a key production factor for many firms, especially in the process industries. The market definition of these companies tends to be global, or at least beyond Germany. Furthermore, although large firms certainly exist, the industry structure remains dispersed. Regulation is a normal factor in the external environment, but not a defining determinant of industry structure and conduct. Profitability tends to be low compared to the standards of the energy industry with operating margins generally below 10%, a testimony to the competitive pressures industry players are subject to. In contrast to electricity generation and transmission companies, firms in energy technology and materials are typically considered very innovative. Electrical engineering, mechanical engineering and chemicals for example occupy top ranks in Germany when it comes to their innovation intensity measured by R&D expenditures and capital investments (Rammer et al., 2014, p. 7). All three are considered research-intensive industries (ibid., p. 2).

It is clear that both value chain steps are of tremendous importance when it comes to the German energy transition. The first one is directly affected by any change to the energy system, the second may as a consequence experience changes in an important customer segment and furthermore have to envisage changes to its own use of electricity and other energy sources in the production process. However, since the electricity generation and transmission industry has not been a stronghold of innovation in the past, it is unclear what can be expected in the context of Energiewende. In terms of public and political attention certainly, the second value chain step and especially those firms of it that belong to the German manufacturing base is where the focus to deliver innovation lies (BMWi, 2012a). This is not a surprise since the strength and the potential of the German economy is typically seen in the producing industries, so this plays well to the targets of competitiveness and a general economic boost due to Energiewende.

The innovation effect at large can only be understood when looking at an entire value chain. For technological innovations at least, invention and implementation tends to sit further upstream, while the diffusion of technology is fostered by the downstream customers. This may not apply to all products and services, but in certain areas such as e.g., energy generation technology this partial split of the innovation process is certainly the case. If one regards the innovation process from a purely technological point of view, electricity generation and transmission contributes to the diffusion of technology through upgrades and new investments into their power generation technology portfolio, infrastructure network or other physical assets. Vertical cooperation e.g., in joint development products can hence be expected to be of importance (Cames, 2010). However, going beyond technological innovations as it is the ambition in this thesis one may expect more such differentiations and mutually beneficial integrations between these steps. Finally, the discussion thus far may be more applicable to incumbents in the respective value chain steps, than to new entrants. This is also a reason why market position was included as a separate firm characteristic in the theoretical framework (cf. section 5.2.4).

6 Findings of exploratory company case studies

Following the elaboration of theoretical literatures (chapter 2), a close look at Energiewende (chapter 3) and the status quo regarding its innovation effect (chapter 4), as well as the development of a theoretical framework (chapter 5), this thesis now turns to its core part, the empirical investigation of the research interest, the effect of Energiewende on corporate innovation.

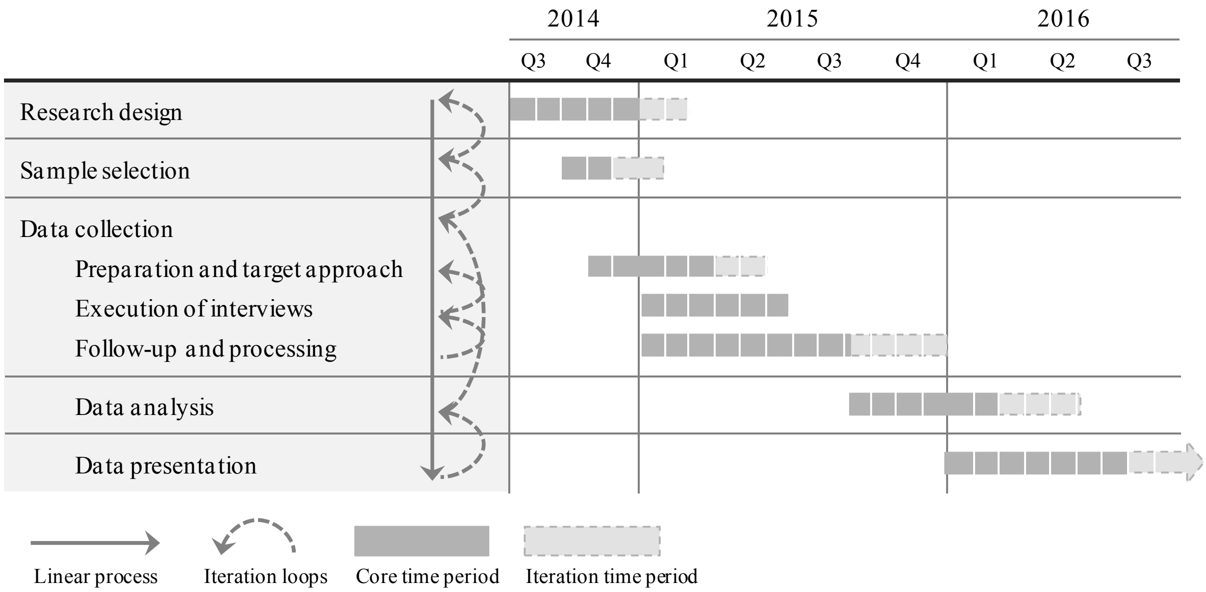
The empirical enquiry employs an exploratory, qualitative research design and investigates the research interest through a series of case studies with firms of the energy technology value chain. While the research has been carried out through case studies, the presentation here proceeds not case-by-case, but according to the empirical research questions that guide the conceptual framework.

This chapter proceeds as follows. First, the research methods and process employed in the qualitative case studies are elaborated (section 6.1). Then, the findings of the case studies are presented by empirical research question with first, the development of innovation activities and innovation dynamics (section 6.2), second, the impact of the individual components of the Energiewende policy mix (section 6.3) and third, the impact of the confounding context factors and firm characteristics (section 6.4).

6.1 Research methods and process

The empirical investigation consists of exploratory case studies of companies in the energy technology value chain employing qualitative research methods. The use of qualitative, exploratory case studies to investigate a phenomenon is especially suitable if little prior knowledge exists and the phenomenon under study is highly complex and embedded so that individual variables and influencing factors cannot easily be identified. Figure 15 provides an overview of the research steps and the timeline associated with them from research design to data presentation. While the research process is depicted in terms of linear, sequential steps it is important to note that iterative loops between individual steps were frequent, which also explains their overlaps in terms of timeline. Following the definition of comparative case studies as the research design, a sample of firms was selected for these case studies according to their relevance to the research interest. Data collection mainly relied on interviews conducted with members of these firms, but was triangulated with public information from company websites, annual reports and secondary sources. The text material emerging from the interviews was coded and analyzed using qualitative content analysis. The results are presented in this thesis not by individual case, but clustered by the elements of the theoretical framework (chapter 5). The following sections are organized by these research steps and further describe approach and methods used in each.

Figure 15: Steps and timeline of the research process



6.1.1 Research design: qualitative comparative case studies

The empirical part employs a research design of comparative qualitative case studies of firms in the energy technology value chain. The firm is the unit of analysis and one firm is designated one case. While the investigation of each case is carried out case-specific through interviews and other means of data collection, cases can be compared as the particular dimensions specified in the theoretical framework are tracked throughout sample selection, data collection and data analysis. The categorization along these dimensions allows the investigation of similarities and differences across and within groups in an effort to be able to deduce results that are applicable beyond the cases in the sample (Eisenhardt, 1989).

This particular choice of research design and methods is appropriate (Flick, 2014, p. 15) for the exploratory research interest of this thesis. Qualitative research has the discovery, exploration and creation of new knowledge as its primary objective (Flick, 2014, p. 11; Lamnek, 2006, p. 81). It builds on the epistemological perspective of social constructivism which holds that no knowledge exists independent of the social and cognitive context in which it is developed and challenges the existence of neutral and objective reality (Berger & Luckmann, 1966; Lamnek, 2006, p. 48). The emphasis of qualitative research is hence on *verstehen* i.e. understanding and interpreting a phenomenon under research rather than the testing and falsification of hypotheses that positivist research traditions rely on (Flick, 2014, p. 90; Lamnek, 2006, p. 216). Therefore it is especially suitable if the phenomenon under study is complex, cannot be captured in a simple, linear cause-effect relationship and therefore needs to be investigated under consideration of its context. Furthermore it can be applied where quantitative methods fail e.g., if there is little existing theory to build on and a limited availability of data because events and processes are current and ongoing. Qualitative research can address research questions with a focus on exploration, such as questions asking what, how and why (Flick, 2014, p. 150). All of these apply to the research interest of this thesis. Case studies are a well-documented and frequently-employed research design in qualitative research. The focus on a limited number of cases allows studying a phenomenon at a great level of detail and under consideration of the specific context it is embedded in (Eisenhardt 1989, Yin 2009). The use of case studies to explore innovation on a firm level was already advocated by Schumpeter (Andersen, 2013; Schumpeter, 1947). With written and verbal text as the main material, qualitative empirical research departs from mathematical and statistical models and turns to interviews, focus groups, participant observation and ethnographies instead (Flick, 2014, p. 43; Lamnek, 2006, p. 266). Given the investigation of a social phenomenon embedded in its specific context employing qualitative research methods no claim to universal validity, applicability and relevance of the research findings can be made (Jahoda, 1989).

The interaction between the researcher and research objects in data collection, the interpretive tradition in data analysis, and the fact that text material is more difficult to comprehend than numerical data warrant particular attention on side of the qualitative researcher with regards to quality assurance. This is made difficult by the fact that established quality criteria for quantitative research such as external, internal, and construct validity, reliability and objectivity are only partially applicable to the questions as well as the method of giving answers in qualitative research (Flick, 2014, p. 487). Thorough foundations of the research design and methods as well as rigorous and transparent execution of the steps of the research process are important to avoid allegations of bias and journalistic style (Spencer, Ritchie, Lewis, & Dillon, 2003). Three steps are taken in particular to ensure academic quality in the qualitative empirical investigation in this thesis: triangulation, process transparency, and the reliance on established and well-documented qualitative research methods. First, triangulation fundamentally means taking different perspectives in research. Instead of relying on one source, it entails deliberately changing perspective and looking at a phenomenon from a different angle (Flick, 2014, p. 183). References to this will be made throughout the following sections. Second, process transparency is important as qualitative research is often lengthy, iterative and deals with verbal and written data that is harder to comprehend, summarize and analyze than numerical data. Also the nature of conducting qualitative research especially in data collection and analysis is arguably more prone to being unduly influenced by the researcher (Flick, 2014, p. 500). Transparency of the research process and reflection of biases and undue influence can certainly only enhance research quality. The space devoted to discussing research methods and process in this and the following sections, as well as a reflection of the limitations at the end of the thesis (section 8.2) seek to establish this transparency. Lastly, throughout the decades that qualitative research has been carried out, researchers have developed suitable and well-documented methods for each step of the research process (Flick, 2014; Lamnek, 2006). The use of these methods will also be detailed in the following sections.

To construct each case, material from different sources of data was sequentially assembled, analyzed and documented. Data from interviews conducted with members of the respective firms form the core of the case studies (cf. section 6.1.3). The temporal perspective taken was mainly retrospective focusing on the time span from the 1990s to the end of 2014. Depending on the interviewee's preferences and knowledge, however, shorter or longer time spans were investigated. The materials making up one case study include an overview of the firm and the interview partner(s) assembled in preparation for the interviews, the interview audio files, coded interview transcripts and a collection of materials from website, company reports and secondary sources. Materials are not included in this thesis as anonymity was a prerequisite to be able to get access to sensitive, non-public information such as innovation activities and the perception of political processes. The sanitized, coded and analyzed interview transcripts as well as the learnings from the other data sources form the basis for the findings presented later in this chapter. The individual steps of the research process will be detailed further in the sections below.

6.1.2 Sample

Firms were selected for the case studies according to their relevance and contribution to the research interest. In qualitative research the selection of cases is purposive and seeks to establish a sample that is relevant and interesting (Patton, 2002). This is in contrast to quantitative research where cases are drawn randomly in order to ensure representativeness. No claim is hence made that the sample drawn constitutes a general representation of its population.

The externally observable firm characteristics included in the conceptual framework (section 5.2.4) were defined as sampling dimensions:

1. Value chain position
   a. Value chain position (energy technology and materials, electricity generation and transmission)
   b. Technology portfolio – range of activities (focused, diversified)
   c. Technology portfolio – sector (8 different ones defined)
2. Industry position (incumbent, start-up)

They define the dimensions and categories of comparison that need to be held constant in order to investigate within and between group differences. The assignment of firms to categories was done by the author using publically available information from the official websites. Firms founded after 1990 were classified as start-ups[1]. Companies with several business units of which at least one is not energy-related were classified as diversified. It was ensured that the selection of cases studied has a sufficient variation with all categories being included in the sample. In addition other information and data pertaining to the sample such as revenue, employees and R&D expenditures were also tracked.

Besides providing for variation on these dimensions, cases were added to the sample based on their substantive contribution to answering the research question. It was ensured that particularly relevant cases were studied incl. large and influential firms, thought leaders on innovation and the environment, firms with managers very vocal about their opinion on Energiewende, as well as firms considered laggards and inert. In this way the ambition was to have include typical cases as well as cases that are deviant (Patton, 2002). Naturally, access

[1] Two exceptions to this were made. First, transmission system operators although founded in the 2000s were labeled incumbents since they were just carved-out from incumbent electricity suppliers. Second, one solar technology firm founded before 1990 was labeled start-up since its major activities only began later.

was critical, too. Given interviews with experienced and senior employees are the core of the data collection strategy, the availability for such an interview was a hard criterion for inclusion in the sample. More details on approach strategies and response rates will follow in the next section (6.1.3). Cases were added in an iterative, step-by-step manner until saturation occurred i.e. new cases did not add new information to the sample (Glaser & Strauss, 1967).

Tables 3-5 below are sampling matrices of the value chain position and the respective other sampling dimensions. They provide an overview of the distribution of the cases across these dimensions. The sample consists of 27 cases in total, 11 of which belong to different sectors in electricity generation and transmission and 16 of which to different sectors in energy technology and materials (Table 8). Of the 11 electricity generation and transmission firms 9 are incumbents and 2 start-ups, in energy technology and materials 11 firms are incumbents and 5 firms are start-ups (Table 9). All 11 electricity generation and transmission firms have a range of activities only focused on energy, while of the 16 energy technology and materials firms only 7 firms are focused and 9 firms have a diversified portfolio of activities (Table 10). In addition, Table 11 gives more information on the sample in terms of revenue, R&D expenses and percentage share of R&D of revenue.

Table 8: Sampling matrix 1 (value chain position x technology portfolio – sector)

Value chain position	Tech. (sector)	# cases
Electricity generation and transmission	Electricity supply (national)	5
	Electricity supply (municipal)	4
	Electricity transmission	2
Energy technology and materials	Electrical and mechanical engineering	5
	Chemicals	3
	Solar technology	3
	Software and IT	2
	Heating and climate	2
	Energy efficiency services	1
	Σ	**27**

Table 9: Sampling matrix 2 (value chain position x industry position)

Value chain position	Industry position	# cases
Electricity generation and transmission	Incumbent	9
	Start-up	2
Energy technology and materials	Incumbent	11
	Start-up	5
	Σ	**27**

Table 10: Sampling matrix 3 (value chain position x technology portfolio – range of activities)

Value chain position	Tech. (range)	# cases
Electricity generation and transmission	Focused	11
	Diversified	0
Energy technology and materials	Focused	7
	Diversified	9
	Σ	**27**

Table 11: Revenue and R&D expenses of firms in sample

Indicator	Value	# cases
Revenue 2014 (€ billion)	< 1 €B	7
	1,000 – 10,000 €B	9
	10,000 – 20000 €B	5
	> 20,000 €B	6
R&D expenses 2014 (€ million)	Not reported	8
	< 100 €M	8
	100 – 500 €M	7
	> 500 €M	4
R&D / revenue 2014 (percent)	Not reported	8
	< 1 %	6
	1 – 5 %	9
	> 5 %	4

6.1.3 Data collection

Data collection was centered on interviews with members of the firms in the sample. Interviews were chosen as the preferred method of data collection because of the lack of publicly available data to investigate the research question, as well as the ability to enhance understanding through direct, contextual involvement with case study subjects. Interviews are a method to tap into non-public information and study a phenomenon through the lens of the actors involved in it. Interview data was triangulated with publicly available information from company websites, reports and secondary information sources.

6.1.3.1 Episodic elite interviews as a data collection method

Episodic interviews with corporate elites were chosen as the interview style. Episodic interviews combine elements of semi-structured interviews such as definitions and opinions with elements of narrative interviews such as stories and perceptions. As experiences are "stored and remembered in forms of [both] narrative-episodic and semantic knowledge" (Flick 2014, p. 273), this interview style was especially suitable to investigate the research questions of how firms had perceived the various policy elements of Energiewende and why and how innovation activities had been changed as a result. An interview guide based on the conceptual framework contained a list topics and questions to frame the conversation (cf. section 6.1.3.2 below). However, openness was preserved to new and different turns in light of what the interviewee found relevant to share. Interviewees were particularly asked to recall and retell events that occurred in the past as cognition within an organization is often shared in terms of narratives (Augenstein & Palzkill, 2015).

The interview targets, senior employees with significant experience in the firm, were defined as the "corporate elites". The classification as "elite" is a deliberate distinction to the "expert" interviews common in social sciences. Experts provide an opinion on a topic of which they possess good knowledge. They may have a comprehensive overview of a subject matter and can often claim a neutral, objective standpoint. In contrast to this, elites provide an inside-out perspective based on their personal, first-hand experience (Littig, 2008) which is grounded in the "privileged position [...] and [...] influence" (Richards, 1996, p. 199) they hold or have held. In a corporate context elites are usually identified in a "senior or middle management position [...] with functional responsibility [...] considerable industry experience, and frequently also long tenure in the company" (Welch, Marschan-Piekkari, Penttinen, & Tahvanainen, 2002, p. 613). Interviewing experts produces secondary data, interviewing elites elicits primary data. This was deemed relevant for the research question since it is especially the lack of primary data on an innovation effect of Energiewende that has been contemplated (Löschel et al., 2014c; Rennings & Rexhäuser, 2014).

There are of course several limitations associated with interviews as a data collection method in general and elite interviews in particular. First, interview data is subjective as it is a personal account. It does not necessarily a comprehensive description of a phenomenon and most certainly affected by biases. Second, interviewing one or several individuals that are members of an organization is still only an imperfect representation of the opinions and cognitions of the organization as a whole. While individuals in one organization tend to think along similar lines, they are by no means the same (Daft & Weick, 1984). Interpretation of external events may vary across members of a firm and it is important to note that individual reflections are only an imperfect representation of a point of view that is supposed to hold for the entire firm. However, one can tap into corporate cognition only through its individuals. Third, interviewers will have an impact on the results through the questions they ask and the relationship between interviewer and interviewee that enfolds throughout the interview.

Lastly, in the context of interviewing elites time constraints on part of the interviewee and power asymmetries between interviewer and interviewee may in addition bear on results (Richards, 1996). These shortcomings were addressed through thorough preparation and post-interview review of the results. The following sections describe the individual steps of the data collection process.

6.1.3.2 Preparation and target approach

A generic interview guide was prepared based on the conceptual framework (cf. section 5.2). It consisted of a list of topics to be discussed in the interviews as well as particular questions regarding these topics (cf. Figure 24, appendix). Despite the guide the interviews were kept deliberately open to develop in ways that suggested by the interviewee. This guide was first tested with fellow researchers and then in a test interview with a firm fitting the sampling criteria. Since no changes to the guide were made after the test interview it was decided to include the test interview case as a regular case in the research.

Interview targets were approached between December 2014 and March 2015. Three different sources were used to identify targets: first, personal acquaintances; second, network references, third, cold calls. All targets were first contacted with customized emails explaining the objective of the research as well as the participation required on parts of the interviewee. Non-responses were followed-up by email and phone about four weeks later. In general responses received were very satisfactory indicating a high interest in the research topic. Of 50 requests, 32 individuals (64%) participated in interviews.

Employees in lower, middle and senior level management positions, specific functional departments (innovation, R&D, strategy, politics), and a minimum 2 year tenure were considered best suited to answer the questions at hand. Exceptions to these criteria were made, however, where access and availability mandated to do so and the specific experience of interview targets was still relevant. The organizational unit that the interviewee belonged to was not a selection criterion, but still tracked. Table 12 provides an overview of the characteristics of the 32 interviewees.

Table 12: Overview of interviewee characteristics

Characteristic		**# of interviewees**
Hierarchy[1]	Top management	11
	Middle management	17
	Lower level management	4

Functional department	R&D	8
	Innovation	7
	Strategy	6
	Communications	5
	Politics	4
	Sales	2
Tenure	< 2 years	0
	2-5 yeas	8
	5-10 years	12
	>10 years	12
Organizational unit	Central department in single business firm	16
	Central department in multi-business firm	11
	Independent company in multi-business firm	3
	Decentral business unit in multi-business firm	2

1. Top management = company executives and their direct reports; Middle management = direct reports of top management; Lower level management = other employees with managerial function; Functional employee = employees without a managerial function

In preparation of the interviews data was systematically assembled on the firm and the interviewee. The company website, official documents such as annual financial statements and sustainability reports and the internet were searched for relevant information. Documents and data were identified based on key words (e.g., "Energiewende", "innovation", "company name", "interview name") and selected based on relevance to the research questions. Documents were archived in case study databases. Key financial data was assembled from websites, annual reports, and BCG ValueScience Center, a proprietary database by The Boston Consulting Group, so that a database with financial and innovation-relevant data points case study subjects was set up. Information gained during this research process also served as preparation for the interviews. Figure 25 in the appendix contains an example of the guidelines and data sheet used in interview preparation. The generic interview guide was customized for each interview to be able to talk about firm-specific developments during the interviews (e.g., surge in R&D spent or introduction of an environmental product portfolio) and to challenge the information gathered during the interview process.

6.1.3.3 Execution of the interviews

Interviews were conducted between January 2015 and June 2016 in person or over the phone. In four instances more than one person was interviewed per firm. These were very large firms where it was deemed useful to speak with more than one person in order to capture different nuances of responses. In two instances, interviewees preferred to be interviewed in pairs rather than individually, so 30 interviews were conducted in total. A roughly equal share of cases as well as interviews was maintained across the two value chain steps considered (cf.

Table 13). A full list of interviews and interviewees including title, type of firm and date of the interview can be found in Table 17 in the appendix.

Table 13: Cases, interviews, and interviewees by value chain position

Value chain position	# cases	# interviews	# interviewees
Electricity generation and transmission	11	13	13
Energy technology and materials	16	17	19
Σ	**27**	**30**	**32**

Personal interviews in the interviewees' offices were preferred, but not always possible to schedule due to time constraints and the geographical dispersion of the interview targets across Germany. Therefore of 30 interviews, 18 (63%) were conducted over the phone. Language of the interviews was German since that was the mother tongue of all participants. Interviews were scheduled for 60-90 minutes, depending on the interviewee's availability. Average interview time was 72 minutes. Interviewees were guaranteed full anonymity, control over the data used for research (through review and editing rights to the interview transcript) and access to research results. With the consent of the interviewees all interviews (100%) were recorded, although the recording device failed in two instances.

6.1.3.4 Follow-up and processing

After the interviews impressions were captured in terms of interview memos, and interview data was prepared for analysis. Information provided during the interviews was double-checked with publically available information and the documents and data assembled in the preparation of the interview. Interview records were transcribed between May 2015 and October 2015. Transcription was conducted using the transcription rules described by Flick (2014, p. 389 ff). Transcriptions are word-by-word of all parts of the interviews relevant to the research questions i.e. omitting irrelevant episodes such as introductory small talk. Omissions are indicated in the transcripts. Interviews were made anonymous in the process of transcription. Placeholders were substituted for names of individuals, products, firms and organizational units. In total 29 hours and 42 minutes of audio material were transcribed to 428 pages of text. In the two instances where technical failure prevented audio recording, extended interview memos were drafted instead of transcripts. Interviewees were sent the transcribed document (or interview memo) to review. Only 7 interviewees made minor edits (single words, clarification of names, times) to the respective documents, no statements were substantively changed.

6.1.4 Data analysis

Data analysis was conducted using the transcribed interviews as text material and the content structuring technique of qualitative content analysis (Mayring, 2000, 2012) as main method. Qualitative content analysis is a systematic, but flexible approach to analyze qualitative data by reducing its complexity (Flick 2014, p. 430). The analysis was assisted by the qualitative data analysis tool Atlas.TI.

First, a list of initial codes was drafted based on the theoretical research framework. Second, using this list, the transcribed interviews were coded paragraph-by-paragraph with, in a first step, automatic assignment of codes using key words and, in a second step, manual review of the automatic coding through reading the transcribed interviews in full, checking if codes were assigned appropriately or if codes were missing, and re-assigning codes if necessary. Third, as the result of the review the initial list of codes was extended and changed. Fourth, the analysis proceeded by going through the codes sequentially and reviewing the paragraphs associated with them. Paragraphs were read and re-read, compared, organized and the essence of their meaning extracted. Sometimes sub-categories were developed for a code. Fifth, extracts and codes were woven together for data presentation and in the course of writing this thesis it was decided which of the paragraphs associated with a code would best illustrate the claim made before.

6.2 Innovation activities and the development of innovation dynamics

This section presents the findings of the case studies on how Energiewende has affected innovation activities in the energy technology value chain. It is the answer to the empirical research question:

How have German firms over time changed their innovation activities in the light of Energiewende?

The case studies provide a comprehensive understanding of the innovation dynamics in the context of Energiewende in Germany. They show that significant changes to the innovation activities of the companies surveyed have taken place over the time period studied. The dynamics are presented here in terms of the three categories of innovation activities distinguished in the conceptual framework (cf. section 5.2.1): exploration, development and implementation, adoption, and organizational change. This provides a deep insight into how firms coped with Energiewende and addressed it through their innovation activities over time. It is investigated what changes occurred, when they occurred, which firms or types of firms were affected by and drove these changes and why they acted in a particular way.

Throughout the analysis, the results presented are induced from the case study materials and stay close to the information provided especially during the interviews. Direct quotations from the interviews are therefore used to illustrate the claims and results. While the identity of the source of the quote is concealed, it is indicated what type of firm a quote comes from in terms of market position (start-up v. incumbent), range of activities (focused v. diversified) and value chain position (energy generation and transmission v. energy technology and materials) and/or sector (e.g., energy supply, chemicals) employing the categories defined in section 6.1.2. This is important contextual information and also testifies to the impact of firm characteristics, which will be elaborated in more detail in section 6.4.2 in the subsequent chapter.

6.2.1 Exploration, development and implementation

The case studies show that Energiewende relevant exploration, development and implementation has been carried out by firms in Germany over the past decades and that they have exhibited several changes of dynamics over time. As activities and dynamics vary significantly across the technologies and applications relevant in the context of Energiewende, the analysis is structured along different meaningful groups that emerged through the interviews: renewable energy generation and supply, conventional energy generation and supply, energy consumption and efficiency, smart grid and energy management, and energy storage.

6.2.1.1 Renewable energy generation and supply

The case studies provide evidence for the common perception that renewable energy sources (RES) in general, and technology for the generation of electricity from renewable energy sources (RES-E) in particular, are among the most important target areas for innovation activities in the context of Energiewende. RES was a topic that featured prominently in every case study with participants emphasizing their activities in the area, but also shortcomings and restraints they have or have had in the past.

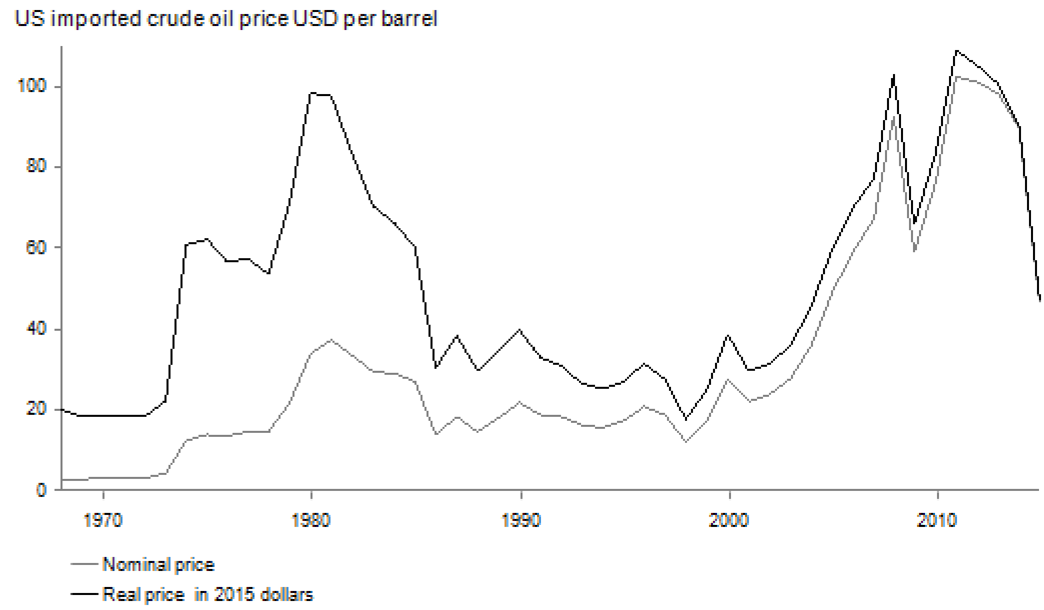
6.2.1.1.1 *Early development and retreat to niche*

A first push to explore and develop technology for energy supply from RES occurred in the 1970s to 1990s following the oil crisis. Especially incumbent energy technology firms and some electricity suppliers started conducting research, development and demonstration (R&D) for various RES technologies incl. wind and solar photovoltaic (PV) and hence laid the foundations of these technologies today.

The major driving factor behind these early activities was the perceived risk to the supply of crude oil as an energy source that was triggered by the first oil crisis. The oil price spikes of the mid-1970s to early 1980s (cf. Figure 16) sparked an interest in developing alternatives sources of energy supply. Furthermore, such investments were promoted by public funding for R&D through the German federal government's Energy Research Program (*Energieforschungsprogramm*) and other public funding initiatives for research in renewables. The Energy Research Program was initiated in 1974 against the backdrop of the oil crisis as the first policy instrument with the explicit objective to support innovation in energy technology (cf. section 3.2).

- "In the 1970s with the […] oil crisis, that is when we started exploring renewable energy." (interview 23-1, incumbent foc. heating tech firm)
- "We started to invest [in R&D] when politics started to become interested in alternative energy. Of course we also reacted to the research subsidies […]." (interview 2-2, incumbent div. electrical/mechanical engineering firm)

Figure 16: Crude oil price 1968 - 2015 real and nominal



Source: Own graphic with data from EIA (2016)

As the oil price resumed to pre-crisis level in the mid-1980s also the perceived need for alternative energy sources declined. Incumbent energy technology and electricity supply firms with the majority of their business in conventional generation did not anticipate a sufficiently large market anymore. Public research subsidies for RES decreased in the late 1980s. As a result incumbent firms often discontinued activities or continued them at a low level to serve the pro-environmental public opinion that had emerged from the environmental movements:

- "We developed solar thermal systems [and other technologies]. […] However, that was still rather crude because subsidies stopped at some point […] and oil got cheaper again." (interview 23-1, incumbent foc. heating tech firm)
- "We had a wind power plant for testing and demonstration [in the 1990s], but this was rather for PR reasons." (interview 7-1, incumbent foc. national electricity supplier)

However, besides the incumbent energy technology firms and electricity suppliers, a bunch of new firms with an exclusive focus on renewables were founded in the 1908s and 1990s. Often these new firms emerged from university research institutes and were a step towards commercializing the technological progress achieved there, or were driven by entrepreneurs with the vision of a green energy future. These start-up firms tended to continue their research activities even when the incumbents dropped out as they expected a market for RES technology in the long run and were incentivized with a strong intrinsic motive of green energy supply.

- "Energy transition was actually the vision when we were founded; to be able to supply from 100% renewable sources" (interview 13-1, start-up foc. solar tech. firm).

They made investments into the development of RES technology, thereby improving its performance and lowering production costs. Significant progress was achieved although the rate of improvement was limited due to financial constraints. One interviewee argued that the technological development observed in renewable energy technology would not have been possible without these "medium-sized enterprises and firms that were just start-ups 15 to 20 years ago" (interview 27-1, start-up foc. solar tech. firm).

6.2.1.1.2 *Market growth and mainstreaming*

It was only in the early 2000s that incumbent energy technology and electricity supply firms rediscovered RES as a viable business and revived their exploration, development and implementation activities. While electricity suppliers contributed towards innovation especially through the investment in adoption and consequential diffusion of RES technology (cf. section 6.2.2.1), energy technology firms focused on business development and technological improvement. Start-up firms only active in renewables expanded their business, incumbent energy technology firms started to create new business areas around RES technology through organic growth or acquisitions. They also invested into expanding the respective areas by developing their RES product offering and conducting R&D.

The major reason for this resurgence was the increasing demand for energy from RES and RES technology and the vast global market potential expected in the medium and long term. Throughout the 1990s the large energy technology firms had observed the RES market, but considered it too small to participate and left it to niche actors and start-ups. It was only when the potential of the market rose around 2000 that they got interested again. A global market offered sufficient revenue potential and globally active energy technology firms considered their ability to provide high quality technology globally as a strength and competitive advantage in comparison to niche players.

The rising market potential was to a large extent politically-induced. The concern about climate change and other environmental effects of fossil fuels had developed into a global trend. In an effort to combat it, government around the world set up targets and incentive schemes for the deployment of RES technology around 2000. Of this global market, Germany made up a significant part, but was still one of many. While it was driven by the attractive feed-in tariff installed through the Renewable Energy Sources Act (*Erneuerbare Energien Gesetz*, EEG), Germany's limited endowments especially in terms of wind and solar irradiation, provided an alleged natural constraint to market growth. The energy technology firms surveyed emphasize their global perspective and consequently the global market potential as the relevant factor in their investment decision for both business development and R&D.

- "In order for us to enter, an emerging industry [such as RES] needs to reach the point where the expected market potential can no longer be exploited by [small niche players]. When they hit their limits regarding processes, global reach, quality, or financing. That was around 2001 and 2002" (interview 10-1, incumbent div. electrical/mechanical engineering firm).
- "[The EEG did] not really drive [our entry into wind] because we have always had a view on the world market. […] It was rather the whole political outlook on renewables and an energy transition, internationally, that provided confidence that the global market […] will develop. " (interview 10-1, incumbent div. electrical/mechanical engineering firm)

For many incumbent energy technology firms in the case studies, the entry into RES technology was impaired by their existing capabilities and resources as well as a cognitive bias towards the established business with conventional energy technology. These factors influenced the decision to start investing as well as the choice of renewable technology to invest in. First, the resources and capabilities which they possessed and which were successful in the conventional energy business were not considered useful for RES. This applies to internal technological capabilities, knowledge and organizational structures, but also to the established business networks and customer base. The target customers for conventional and renewable technology differ significantly. While the conventional energy technology customers tend to be few, large firms, the latter ones are many, small firms or private customers, requiring a different sales and marketing strategy. Second, the nature of RES with their low energy density and consequently the need to supply energy from many small-scale sources instead of large central plants was per definition considered inefficient and for that reason not viable to develop into a proper market. A "this cannot work anyway"-attitude was common. This bias is why it was for most companies easier to invest in wind rather than solar PV. Wind technology was much closer than PV to the business of conventional fossil-fuelled power plants due to comparatively larger capacities, low generation costs and an industrial rather than residential customer base.

- "We wanted to get away from fossil fuels. […] We just did not find a way to enter that PV market, the internal barrier was our inability to define a unique selling point. […] We used to say "well, wind turbines spin", so that is not too different to our conventional generators" (interview 2-2, incumbent div. electrical/mechanical engineering firm).
- "We are very happy in our role as a supplier [in business-to-business transactions]" (interview 25-1, incumbent div. electrical/mechanical engineering firm). "With wind, especially offshore, it's always large industrial clients. That suits us" (interview 2-2, incumbent div. electrical/mechanical engineering firm).

In addition to skepticism regarding the viability of the technology and associated business model, the established technology and materials firms were also wary to get into businesses that they felt were overly influenced by politics and hence oversubsidized. Markets that were dependent on revenues not sustained by market forces were considered too risky. While this is surprising given that the electricity industry as major customer base for energy technology has been regulated and in fact often state-owned since its foundation, several case study participants stressed this aspect. To a certain extent this conviction was abandoned as the market entries did take place, but caution was maintained and a future without subsidies anticipated in the planning process.

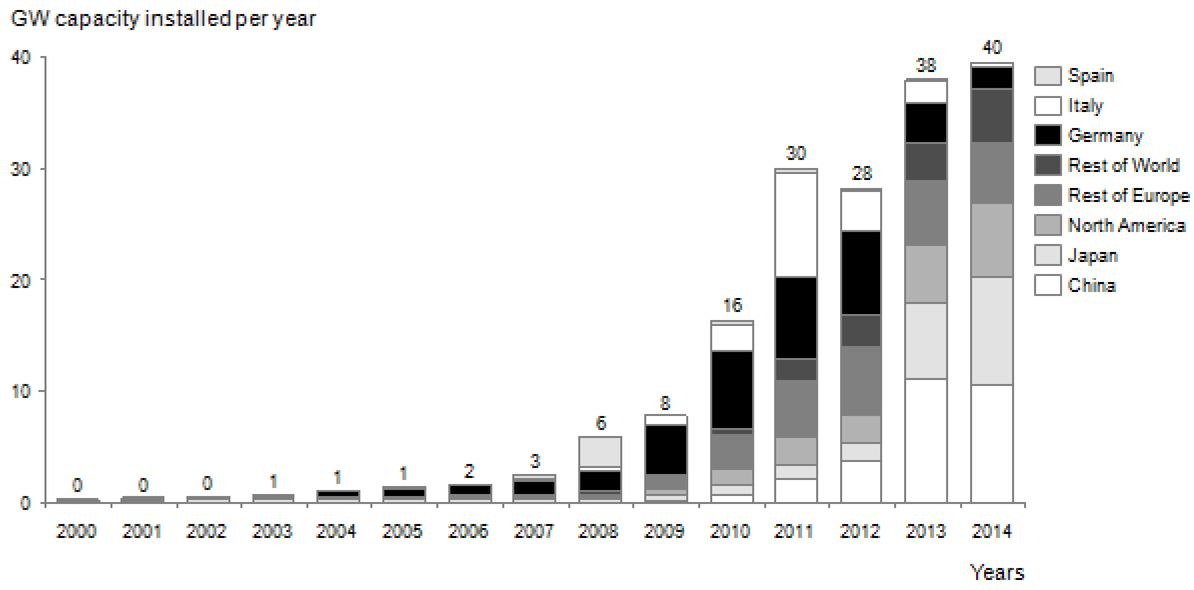
- "We had something almost like a dogma, definitely in the 1990s, but also afterwards in the 2000s […]. We don't go into subsidized markets." (interview 2-2, incumbent div. electrical/mechanical engineering firm)
- "If my business case depends on returns that are not generated by market mechanisms I run a portfolio risk. […] This is not sustainable from a business perspective and that is why we are strictly against it." (interview 21-1, incumbent div. chemicals firm)
- "That's too volatile, too insecure. […] We would of course still gather experience with pilots and small projects, [but not make a full market entry]." (interview 2-1, incumbent div. electrical/mechanical engineering firm)

- "This only changed when we entered wind. […] [However,] we also held the opinion that wind was the first technology that would work without subsidies." (interview 2-2, incumbent div. electrical/mechanical engineering firm)

While the global market growth was critical for investments into R&D in the first place, the case studies also reveal that it created a certain tension between investing in technological development and investing in production capacity. This was found to be the case especially in solar PV[1], an industry that went through a boom-and-bust cycle in the 2000s. While the solar PV market has expanded globally since 2000, dynamics have varied across countries. Germany, which constituted more than 50% of the world market for most of the 2000s, had a boom after 2003 with growth rates well beyond 100% per year. Installations reached peaks of around 7 GW each year in the years 2010 to 2012, only to break down by 50% each year in the subsequent years 2013 and 2014. Italy and Spain experienced similar cycles. These countries had seen the installation of subsidy schemes that incentivized residential and small scale installation of RES-E technology with an attractive and secure feed-in-tariff (FIT) and therefore accounted for the high number of installations demanded in Germany most noteworthy through the Erneuerbare Energien Gesetz (EEG). Subsequent cuts in the subsidies because of the 2008 financial crisis and rising criticism caused a market crash after 2012. As the European market faded, growth was picked up, however, by China and Japan, who today make up 25% of the world market each with capacity additions of around 10 GW per year (compare Figure 17).

[1] It should, however, be noted that solar technology is the only area of RES where focused firms were investigated in this empirical enquiry.

Figure 17: Annually installed solar PV capacity by country 2000 - 2014



Sources: Own calculations based on IRENA (2015), EPIA (2009) and IEA PVPS (2012)

The turmoil of the solar industry affected successes and failures of industry participants as well as exploration, development and implementation activities in the industry. The high growth rates in solar PV installations in the 2000s sparked industry-wide investments in production capacity to reap the benefits of market growth through higher sales. Euphoria was high as standalone solar technology firms as well as solar subsidiaries of diversified engineering companies were doing well. Indeed R&D expenses dropped in relation to sales for most firms surveyed between 2007 and 2010. Hence when demand was at peak some firms tended to exploit the current market opportunities instead of continuing to invest in R&D at the same rate as before.

- "We were completely sold out in 2009/10, there were not enough solar modules in the market. […] That is why we started a massive investment program [in manufacturing] in 2010." (interview 19-1, start-up foc. solar tech. firm)
- "There was a phase in which many of the established PV start-ups […] were intoxicated [by their success]. However, with success and alleged stability, money was squandered. […] Large parties were thrown and money invested in everything from headquarters to sales networks to factories all over the world. […] Completely inefficient and at the expense of the core technology." (interview 27-1, start-up foc. solar tech. firm)

In addition, Chinese firms emerged as competitors adding production capacity and putting downward pressure on costs. Technological know-how especially around machinery and production processes had spilled from Western companies and was put to use. "We produced in China and transferred know-how to our partner, until they did not need us anymore," describes a solar PV manager (interview 27-1, start-up foc. solar tech. firm). Soon global production capacity was about twice as large as global demand and prices dropped in light of the massive overcapacities. PV module performance of comparatively higher-cost producers in Europe and North America was not sufficiently superior to justify higher costs. In addition, module prices dropped below product costs. Many solar firms saw their competitive edge fade away. Diversified firms exited the market. Specialized solar PV firms stayed if their financial situation permitted them to do so.

- "We are good at bringing products to industrial scale […] large quantities, good quality, competitive prices. However, it turned out that solar cells could not be sufficiently differentiated. We were unable to produce significantly better solar cells than a low cost provider. That led to our exit [in 2013]." (interview 25-1, incumbent div. electrical/mechanical engineering firm)
- "As a pure PV player we are only able to do PV. We cannot act like a corporate and [disinvest]" (interview 27-1, start-up foc. solar tech. firm)

The firms that stayed in the market with a view on its long-term potential re-installed their investments in technological improvements. R&D intensity picked up again after 2011.

6.2.1.2 Conventional energy generation and supply

The case studies reveal that besides expanding into renewables, incumbent energy technology firms as well as electricity suppliers continued to invest in the exploration, development and implementation of conventional, fossil-fuel based energy technology. Activities in this area were highest in the mid 2000s and the focus was on reducing greenhouse gas (GHG) emissions through increasing the efficiency of conventional generation and preventing GHG from getting into the atmosphere.

6.2.1.2.1 *Exploration of carbon capture, utilization and storage*

Investments into the exploration of carbon capture, utilization and storage (CCS) surged in the mid- to late-2000s. Firms from all steps and sectors of the energy technology value chain showed interest and invested in R&D for CCS. Similar to the development in RES technology, these investments were especially driven by the global market demand expected for CCS technology. The threat of climate change had become a mainstream societal concern in the mid 2000s. Politicians around the globe were devising policies to prevent it and as a consequence firms were anticipating a market potential in all areas relevant to reducing CO_2 emissions, not only the previously discussed RES. Especially the adoption of emissions trading in several countries, including the EU emissions trading scheme (EU ETS) in 2005 forged expectations that CO_2 emitted into the atmosphere would be priced in the future and therefore the demand for technology to prevent such emissions would rise.

- "Climate change and global warming were important topics." (interview 7-1, incumbent foc. national electricity supplier).

In addition to market potential, the reason why many firms were fond of CCS was because it addressed the problem of carbon emissions without changing the traditional, fossil energy sources coal, oil and gas. Therefore fundamentals of the energy industry regarding customer base, industry structure and technological basics would remain unaffected. This indicates the same bias towards conventional energy because of resources and capabilities as well as cognition that prevented incumbent energy technology firms to invest in RES. Especially for industry participants with reservations towards renewables, CCS constituted an alternative way to combat climate change. CCS testing and demonstration plants were constructed, often in vertical collaboration between technology or materials firms and electricity suppliers.

- "From around 2006 we invested increasingly in CCS." (interview 7-1, incumbent foc. national electricity supplier)
- "The peak [of our R&D investments] was between 2009 and 2011." (interview 20-1, incumbent div. electrical/mechanical engineering firm)

Lastly, the development of CCS technology was supported by public research funds in Germany as well as the EU.

However, CCS lost its allure and investments ceased when carbon prices of the European Emissions Trading Scheme dropped during the financial crisis in 2008/09 and stayed low due to low demand and overly generous allocations of permission permits. Furthermore, tests had been less successful than expected and political standards got stricter due to safety concerns. In Germany this route is today considered closed and also internationally the business prospects seem slim.

- "We were heavily engaged in technologies to reduce carbon emissions. We developed CCS and would have been able […] to provide customers with solutions. [But then the market did not come]." (interview 2-2, incumbent div. electrical/mechanical engineering firm)
- "We realized in 2012 that CCS […] is not a global topic and will only work in a few markets. […] In Germany it was replaced by energy storage." (interview 20-1, incumbent div. electrical/mechanical engineering firm)
- "We dismissed CCS […]. It is not sustainable to put CO_2 in tanks […]. And the locations where CO_2 is produced are not good places to put it in the ground. These are reasons for us to say, if we want to get rid of CO_2, we need to do that differently." (interview 21-1, incumbent div. chemicals firm).
- "We have reduced CCS to observer status. […] It is not a solution for us because we cannot imagine to have the right political framework to be able to finance the large investments required […]. Nobody in the energy industry will invest in this." (interview 6-1, incumbent foc. national electricity supplier)

6.2.1.3 Energy consumption and efficiency

Not only on the generation, but also on the consumption side, exploration, development and implementation envisaged changes in dynamics in the context of Energiewende. The case studies show that while energy efficiency has always been an important topic for the internal processes of firms, especially in energy-intensive industries, the strive to improve processes and develop products for enhanced energy efficiency in various applications got a new dynamic in the mid- and late 2000s.

6.2.1.3.1 *Improving the energy efficiency of products and processes*

The first deliberate attempts to increase the energy efficiency of products and processes were made after the oil crisis in the 1970s. Energy technology firms in a variety of areas became conscious of energy consumption and initiated R&D and other activities to find ways to become more energy-efficient in their products and processes. Process improvements might involve organizational change, e.g., through improved energy management procedures and rules, and are often not formally defined as research projects, which means expenses are not tracked in R&D.

As energy constitutes a cost factor in the production process as well as in the lifetime usage of a product, reducing the energy required clearly provides an innovation incentive to companies due to the cost savings expected to be achieved. In industries where the largest part of energy consumption occurs during the production phase, firms focus on the energy efficiency of their production process. For products that are energy-intensive during their lifetime, the focus lies on reducing energy consumption of that product.

- "Energy efficiency has always been important and will always be important, particularly in industries where energy constitutes a large part of the costs." (interview 10-1, incumbent div. electrical/mechanical engineering firm)
- "In our opinion energy efficiency has always been an important driver." (interview 8-1, incumbent foc. heating tech firm)

The major driver in the 1970s was that the price of oil and other fuels was high following the oil crises and customers were increasingly considering energy costs in their decision to purchase products. Demand for energy-efficient products was hence expected to increase. In addition, public funds for exploring possibilities to reduce fuel consumption became available, especially since the introduction of energy consumption as one development area in the second Energy Research Program of the German federal government in 1981.

With regards to recent dynamics, many firms note that the importance of energy efficiency in product development and internal processes rose noticeably in the mid to late 2000s. Particularly noteworthy is the components and materials sector, where the chemical firms surveyed increased energy-related R&D expenditures and even set up special research units for energy topics incl. energy efficiency. As an energy-intensive industry, the chemical industry has traditionally been conscious about the security as well as the costs of its energy supply. However, since the mid 2000s the importance of the topic rose even more and energy topics in general, and energy efficiency in particular, did also come to be regarded in terms of a business opportunity. The main reason behind energy efficiency's surge in importance for chemical companies was the expected increasing global demand for energy efficient products. Once again the global political initiatives to reduce GHG emissions as well as the expectation and fear of higher energy costs triggered investments in R&D. In all of this German politics and the German market were important, but the companies surveyed agreed that they defined their market on a global scale.

- "We founded a [research centre] for energy efficiency [in 2008] […] and have since then developed and […] launched products. […] Addressing our own internal energy consumption because it reduces costs is a relatively new addition to our activities." (interview 21-1, incumbent div. chemicals firm)
- "We are looking at energy in two ways […] traditionally as a factor of production […] and for a couple of years now as a business opportunity." (interview 24-1, incumbent div. chemicals firm)
- "Reducing our energy consumption has always been a topic […] and an area of activity, but it got an additional push through [global energy transitions]. We are providing more internal funds now for research in order to stay at the forefront." (interview 26-1, incumbent div. chemicals firm)

In general, a combination of factors has influenced these dynamics in energy efficiency. First, the potential for cost savings is an important motivation discussed several times, although no interviewee has explicitly mentioned rising energy prices as a driver for the recent dynamics. Moreover, the European and German long term targets for a reduction of the overall energy consumption as well as regulation around energy efficiency such as standards, labels and certification requirements have triggered investments. Lastly, the availability of public funds for R&D has driven energy efficiency invention and implementation on the product side.

- "[German and European] energy efficiency targets […] are the foundation of our business. […]The European commitment to energy efficiency with the ERP directive was critical. The topic would not have been tabled in Germany otherwise." (interview 12-1, start-up foc. energy efficiency services provider)
- "The ERP directive […] mandates us to only use very energy efficient or renewable technologies in Europe. […] This occupies product development." (interview 8-1, incumbent foc. heating tech firm)
- "Framework conditions change from one day to the next. […] That is not investment security." (interview 12-1, start-up foc. energy efficiency services provider)
- "Markets have been created that do not work because of economic criteria, but because of bureaucratic ones, [energy management systems and certification requirements, for example]." (interview 25-1, incumbent div. electrical/mechanical engineering firm)

6.2.1.3.2 *Energy efficiency as a service business*

In addition to energy efficiency in physical products and processes, energy efficiency also emerged as a service business from the mid 2000s onwards. Firms that provide energy efficiency services give advice how to reduce the costs of energy consumption and design and implement technological as well as non-technological solutions to this end. Clients of such services can range from large industrial firms to individual households. Electricity is not the only form of energy that energy efficiency firms target with their service offering; also heating and cooling or the provision of gas and steam is part of the portfolios.

Incumbent electricity suppliers and energy technology firms have expanded into this business area increasingly since the mid 2000s, often by setting up specific departments or business units for this service. In addition start-ups have also been founded for specifically that purpose. For incumbent firms energy efficiency services tend to complement their physical product offering and serve their existing customer base: Electricity suppliers, esp. the municipal ones, typically focus on residential and small commercial clients, the energy efficiency consulting units of energy technology firms cater to industrial and large commercial clients.

Invention and implementation in energy efficiency does not take the form of developing a specific technology, but rather to find better ways of linking technological products in an effort to develop solutions to make energy supply and usage more efficient. As such not all firms do technological R&D, but instead attribute their innovation activities to developing non-technological solutions for clients often through business development or project-specific work.

- "We founded an energy services company in 2012 [following a project-based exploration of decentral energy management since about 2009]. […] Our business is to develop rules, criteria and simulations to support [energy efficiency in] the value chain." (interview 25-1, incumbent div. electrical/mechanical engineering firm)

Invention in energy efficiency, esp. where it is concerned with process improvement and the developing of consulting services may not be reflected in R&D expenses.

The drivers behind business development and innovation in energy efficiency services are very similar to those for energy efficiency in products and processes; mainly pressure to reduce energy costs because of the expectation of higher energy prices and regulation. However, energy efficiency service providers stress the role of politics even more than firms that are focused on increasing the energy efficiency of their products and processes do. Especially the legal requirement to implement a certified energy management system in order to be exempted from contributions to the financing mechanism (*EEG Umlage*) of the Renewable Energy Sources Act created a sudden boost for energy efficiency consulting overnight when it was first implemented in 2014.

6.2.1.4 Smart grid and energy management

So far the discussion of exploration, development and implementation in the context of Energiewende has only focused on energy supply and energy demand. However, the case studies reveal that from the mid 2000s onwards the focus of innovation activities shifted increasingly from supply and demand towards the link between the two and the energy system as a whole.

This systemic perspective on energy gained importance as the consequences of high electricity generation from renewables became apparent throughout the 2000s. Generation had become more decentral with thousands of small-scale producers of electricity from renewable energy sources. Electricity consumers had turned into "prosumers" who take electricity from the grid as well as feed into it hence requiring additional functionality from a grid network that was originally installed only for the distribution of electricity. Furthermore, the volatility of the supply of electricity from renewables and the geographical divergence between centers of supply and demand put a strain on the transmission grids and increased the call for changes to the system. In addition to adding capacity to the physical grid infrastructure (cf. section 6.2.2.3) and developing energy storage solutions (cf. section 6.2.1.5), the answers were sought through exploring better ways to manage the amount and timing of electricity fed in, transported with and taken out of the existing grid and.

There is a variety of terms to describe the methods, approaches and tools to this end, incl. smart grid, energy management, virtual power plant, demand side management and demand response. The terms are overlapping and often not mutually exclusive. However, with the exception of improved physical grid technology (cf. section 6.2.1.4.1) they all refer to information technology (IT) based products that have data processing as a central element. The objective of all is to increase the reliability, flexibility and efficiency of the electricity grid network. Firms active in this area include incumbent and start-up energy technology firms and electricity suppliers, but also firms that are traditionally not active in the energy technology value chain, such as IT and high tech companies.

Smart grid and energy management technology has applications for the electricity grid directly, as well as for electricity generation and consumption i.e. the supply and demand sides. Rather than changes to methods and absolute amounts of electricity production and consumption, energy management is concerned with the timing of electricity supply and demand in an effort to increase flexibility. Being able to adjust patterns of electricity production and consumption may alleviate strains on the electricity grid and reduce the risk of blackouts.

6.2.1.4.1 *Managing grid capacity and utilization and improving grid technology*

Energy technology firms as well as energy materials firms started to invest in R&D for developing improvements to the grid in the mid 2000s, often in collaboration with distribution system operators (DSOs) and transmission system operators (TSOs) as system operators are directly affected by the changing requirements of the energy infrastructure brought about by the energy transition. New functions and applications were aimed at making grids fit to cope with decentral electricity feed-in, fluctuations in the supply of electricity from renewables, and geographical divergences between centers of supply and demand.

Software plays an important role in that respect. Software for grid management can help address many restrictions of transmission and distribution grids and is cost-efficient compared to extending or renewing the physical grid infrastructure. Software can for example improve grid utilization as close monitoring and management of the grid decreases the safety margin needed to run it without a risk of excessive heat or voltage. This can ease the capacity restrictions of transmission grids, which can occur when large amounts of electricity need to be transported from a place of production to place of consumption.

- "Since the first EEG [in 2000] we have been actively observing the system. […] Since the mid 2000s […] we have developed [software] to be able to better cope with the feed-in of renewable energy, the volatility of generation, bottlenecks in long-distance electricity transmission and running grids at maximum capacity. Information technology is key to control these." (interview 1-1, incumbent div. software/IT firm)

The reasons for seeking to develop ways to improve the grid can be found in the changing demands to the grid infrastructure that emerged over time. Manifestations of this change came in terms of incidences of capacity restrictions, overvoltages and blackouts. A blackout across Europe in November 2006 when a shutdown of a major transmission line incidental with high electricity generation from wind power caused an overloading of the remaining transmission lines was by one interviewee noted as an eye-opening event for finding ways to improve grid performance. TSOs and DSOs have to address such changes as they are by law required to provide grid access and ensure grid stability. Energy technology and materials firms hence saw a market demand developing from TSOs and DSOs in Germany, but also in other countries that are going through a similar energy transition with decentral generation and renewable energy. In addition, as electricity grids provide a service to the wider public, R&D in these areas was often supported by public funds.

In addition to grid management, however, energy technology and materials firms also started to explore ways to improve the physical substance of the grid through using different materials or components in power lines and interconnectors.

- "About 2.5 years ago [in 2012/2013] […] we looked at the electricity value chain […] and realized there are areas where a technological leap forward is possible […] and has significant business potential. […] One area is efficient power transmission with superconductors." (interview 24-1, incumbent div. chemicals firm)

6.2.1.4.2 *Supply side energy management*

On the supply side, energy technology firms and electricity suppliers develop solutions to manage decentral, renewable electricity generation capacity. So-called virtual power plants (VPPs) pool several small-scale power generation units in order manage them in an integrated way. Management includes the operation of the power units and the marketing of electricity output in an effort to maximize returns of the pooled capacity. The amount of electricity fed into the gird can be varied depending on electricity price signals e.g., to benefit from high prices in times of supply shortage or to avoid penalties when actual electricity production diverges from planned electricity deliveries as may especially be the case in terms of fluctuating RES. Generation units can usually be accessed from remote, switched on or off, or electricity be diverted to or extracted from storage if storage units are integrated as well. VPPs can consist of only renewable generation capacity, a mix between renewable and conventional, or conventional only. Very often gas-based power plants are integrated into VPPs, especially such combined heat and power (CHP) plants where the primary purpose is to provide heat and electricity is just a by-product.

Incumbent and start-up energy technology firms and electricity suppliers began to develop VPP applications around 2010. Some account for these development costs in R&D, but many firms do not. First market launches of the resulting products and services started around 2013/2014. Interviewees confirm that there is a lot of activity in the market, but that no dominant players or business models have emerged yet. Three applications of VPPs are currently being explored in particular: VPP as a software or platform, VPP as a service offering and VPP for internal optimization and cost reductions.

First, firms from several backgrounds such as software and IT companies, dedicated energy technology start-ups, but also electricity suppliers are developing the software or platform needed to manage a VPP in order to license it to customers.

- "We developed [software for VPP applications] very early on […]. But only since 2014 we are finally in the position to have relevant pilot customers […] as the topic is developing speed. […] Grid operators have extended their control systems to involve VPP functions […], also independent [non energy] players are active." (interview 1-1, incumbent div. software/IT firm)
- "We are offering our tool to third parties […]. This is a major step towards software solution." (interview 18-1, start-up foc. national electricity supplier)

Second, firms who have developed and operate a VPP use it to provide a management and marketing service to owners and operators of power plants:

- "We are offering […] to take over resource planning and electricity marketing. […] Plants are […] often erected especially for the provision of heat; the electricity is supposed to be marketed as profitable as possible on top of that" (interview 18-1, start-up foc. national electricity supplier).
- "We are offering this as a service to our large and industrial customers" (interview 4-1, incumbent foc. municipal electricity supplier).

For electricity suppliers, this offering often emerged from previous services such contracting, electricity trading or direct marketing of RES-E volumes. Contracting denotes the physical operation and management of power plants on behalf of their owners, often manufacturing firms and industrial parks. This is a core service offering especially of municipal electricity providers. Electricity marketing and trading involves the provision of market access, risk management and portfolio optimization services, all capabilities necessary since traded electricity markets developed after liberalization in the late 1990s and early 2000s. Trading floors are typically operated only by the national electricity suppliers and larger municipal ones who then take over the respective services for smaller players on a contractual basis. Provisions for the direct marketing (*Direktvermarktung*) of RES electricity i.e. without selling it to the transmission systems operator (TSO) were installed in the EEG 2012 amendment as way to introduce market mechanisms into the promotion of RES-E technology and decrease the dependence on outright subsidies. Owners of RES-E generation capacity need access to electricity markets in order to benefit from the guaranteed market premium and often rely on electricity suppliers with such access for that service.

- "The hard thing about VPPs is […] the technical interface. Qualification of the power plants, connecting them physically, the information technology bit. Explaining the customer what remote direct access means." (interview 15-1, incumbent foc. municipal electricity supplier)
- "Intelligent portfolio management is the essence [of VPPs]. We have been doing that for some time. It has emerged step-by-step since we developed energy trading in the early 2000s. […] The only novelty is now, that one has to be able to even more directly access and remote control the operation of customers' plants." (interview 4-1, incumbent foc. municipal electricity supplier)
- "We take on RES production capacity that falls under the EEG. This works especially well with wind, because the plants can be controlled from remote and are therefore easily regulated and pooled. […] We have been doing this basically since the introduction of the market premium in 2012. […] The VPP is reality so-to-speak." (interview 6-2, incumbent foc. national electricity supplier)

Third, firms use VPPs to manage the fluctuations from their own RES-E generation and smooth them out before electricity is fed into the grid in order to increase compliance with the pattern of electricity supply communicated to TSOs in the planning phase:

- "Our focus is on [reconciling] fluctuating wind energy with [our commitments to deliver electricity into the grid]. […] To avoid the financial risk from penalty payments and […] to address fluctuations in the electricity supply in general" (interview 17-1, start-up foc. national electricity supplier).

The main reason to develop VPPs was hence the perceived market demand from network operators and electricity suppliers to find a solution for managing decentral generation capacity in an integrated manner and better address the fluctuations from RES-E. Firms surveyed with a geographic focus on Germany emphasize the consequences of the German energy transition as the root cause of this need, while firms with global activities proclaim similar needs across several countries. In addition to the change of the energy system as such, this demand was furthermore supported by systemic regulation that penalizes non-compliance with electricity schedules planned in accordance with the grid accounting and planning system (*Bilanzkreismanagement*). These penalties set a financial incentive to develop a solution for flexibility and improved compliance with the planning system.

6.2.1.4.3 *Demand side energy management*

Also on the demand side there are business activities to increase the flexibility of energy consumption. These activities are usually called demand side management or demand response. Demand side management came up in the late 2000s parallel to the interest in the supply side. The idea is akin to that of the management of distributed generation; sources of electricity consumption are pooled in an attempt to shift the timing of consumption in response to the supply-demand balance and electricity market price signals. Energy management of supply and demand side are in fact opposite sides of the same coin, they have similar requirements in terms of being able to control electricity generation or consumption from remote and in response to market signals. VPPs and demand side management can work in one system and firms often offer both.

Activities are typically distinguished by type of energy consumer; large, industrial consumers versus residential consumers. While there is general agreement that due to the relatively large consumption of energy per unit in industry compared to private households, industry constitutes a much larger lever for demand side management than residential customers, a lot of business activity revolved around households. Especially municipal electricity suppliers became enthusiastic proponents of smart meters, which are devices that measure electricity consumption and are able to transfer consumption data digitally in order to establish transparency and eventually manage consumption in a better way. The idea was to motivate consumers to move their electricity consumption to times with lower prices or to pool such devices in order to be able to manage electricity consumption centrally. The initial drive for smart meters was brought about by European regulation mandating their use that was implemented in Germany in 2012. However, the coordination needed to connect thousands of small consumers turned out to be difficult to establish and households did not seem to be motivated to change their consumption behavior for the relatively minor reductions in their electricity bills.

- "All pilots in private homes have come to the conclusion that only a small fraction of electricity consumption can be moved in time. […] It's really sobering." (interview 1-1, incumbent div. software/IT firm)
- "Smart meters are a waste of tax payers money" (interview 16-1, start-up foc. software/IT firm)
- "[When it comes to smart meters] we have been cautious, not like some competitors. […] We had selected initiatives […] just to learn. […] Customers are only interested for about two weeks if they don't have a direct benefit." (interview 15-1, incumbent foc. municipal electricity supplier)
- "Our customers consume [such small amounts], I don't see energy suppliers bothering to managing this" (interview 17-1, start-up foc. national electricity supplier)

For industrial applications, demand side management seemed more promising:

- "The effect is much larger in the commercial and industrial segments. It is also much easier to realize economic benefits than with washing machines." (interview 5-1, incumbent foc. municipal electricity supplier)
- "Demand response seemed a no brainer to me. Everything else is expensive or risky […]. It's software and internet, that comes basically for free, and it works with the existing infrastructure." (interview 16-1, start-up foc. software/IT firm)

The topic was picked up by start-ups and to a certain degree incumbent energy technology companies emerged since around 2009/2010 in an effort develop and launch software and tools for demand side management. The idea was to provide a service to distribution and transmission system operators through pooling large electricity consumers and shifting their consumption by minutes, hours or even days if the grid and market situation required them to do so.

- "In 2009 when we started looking at the German market, we could not believe that there was no demand response yet. The energy transition was confined to renewable electricity supply. On the software side […] there were pilots, nothing that actually was integrated in the market." (interview 16-1, start-up foc. software/IT firm)

However, while the concept of demand response was generally embraced, firms found that the regulatory system that governs electricity grid and market access constituted a barrier which was difficult to surmount. The regulatory framework is built on and hence reinforces a specific set-up of the energy system with defined roles and players. This made it difficult to establish new approaches that were not provided for in the regulations.

- "We did find customers, industrial firms were happy to speak to us. But at the same time we always had to be aligned with every other player in the energy industry, that's what the regulation provides for. […] Market access regulations and energy accounting systems are monstrous. […] We did not have a role in the system. The business of demand response aggregation is not provided for in the regulatory frameworks. […] We would have had to cooperate with or become electricity suppliers. […] It works in other countries, but not in Germany." (interview 16-1, start-up foc. software/IT firm)

Just as with supply side energy management, the driver of demand response is the market demand to find a solution for the changing energy system and increase the flexibility of the system to accommodate fluctuating RES-E. This demand emerged as a consequence of the higher RES deployment following the EEG feed-in-tariff in Germany. However, while exploration, development and implementation for demand side energy management have surged since about 2010 it is often the inadequacy of systemic policies such as rules regarding electricity market access that impede further business development in that area. Insecurity in which direction the market for demand response is going does also contributes to this.

6.2.1.5 Energy storage

Another business area that has seen a surge in activity is the development of energy storage solutions. In addition to increasing the grid capacity and shifting electricity supply and demand, storing electricity provides another way to cope with fluctuating electricity feed-in and strains on the grid.

6.2.1.5.1 *Improvement and systemic integration of energy storage technology*

Energy technology firms as well as electricity suppliers have been exploring and developing energy storage technology as well as solutions for embedding it in the energy system since the late 2000s.

- "The topic of energy storage […] has gained importance in the past 2-3 years." (interview 20-1, incumbent div. electrical/mechanical engineering firm)

- "Besides the fact that the ideas have been around for ages, the need for systemic solution [incl. off-grid with energy storage] gained attention in 2005/06. However, corresponding products […] have only been developed since 2009/10." (interview 13-1, start-up foc. solar tech. firm).

Electricity storage can take several forms, which are all still being explored in parallel to one another. The classical and well-established option is use of hydroelectric power plants. Through the operation of the water pumps to transport water uphill electrical energy is converted to kinetic energy and preserved in that way. The subsequent downhill flow of water powers generators that transform it back to electrical energy. To date this is the only established large scale solution for electricity storage. However, other technologies such as power-to-gas or batteries are now in focus of innovation efforts. Power-to-gas storage systems use electrolysis to convert excess electricity to methane and feed it in the natural gas grid or gas tanks for storage. The gas can then be used for multiple purposes such as powering environmentally friendly vehicles with fuel cells or gas engines, producing heat, or generating electricity in gas-fuelled power plants. Lastly, batteries can be used as energy storage devices as electrical energy is converted to chemical energy during the charging process. Batteries can be installed at RES-E power plants in industrial as well as residential settings to absorb the excess electricity that cannot be fed into the grid at the time of production and release it again at a later point in time. For residential applications batteries are getting increasingly important in so-called off-grid systems. Off-grid systems serve households that aspire to be self-sufficient and produce electricity and possibly heat through solar systems or combined heat and power (CHP) on a micro scale. These households only feed into or take energy out of the grid if prices are attractive enough to do so. Batteries provide a way to bridge electricity shortages or carry over stored electricity to sell it at higher prices in the future. Also electronic vehicles use batteries and a fleet of such vehicles could constitute a system for decentral, mobile battery storage.

As explained in the previous section (cf. section 6.2.1.4) energy storage is a possible way to cope with the fluctuations of electricity from renewable energy sources by storing excess electricity instead of feeding it into the grid immediately and thereby possibly destabilizing it. The exploration, development and implementation activities seen are a response to the demand for such solutions that emerged after the growth in the deployment of RES-E in Germany exposed the shortcomings of the current grid infrastructure. Indirectly this was triggered by the German EEG, which caused the mass deployment of RES-E.

Exploration, development and implementation activities regarding energy storage is also often supported by public R&D funds.

Case study participants have noted that to some degree business development in energy storage is impeded because no market for electricity from storage has been defined. Storing electricity and selling it later is more expensive than feeding it directly into the grid, yet both are rewarded equally via the electricity price. In that way energy storage suffers from similar regulatory barriers than those that have been described in the context of demand management above; since the current system does not provide for energy storage its integration into the market and consequently the ways to make money with it are limited.

- "There is little progress in energy storage […] because there is no market. Pumped hydro storage has traditionally worked because of a day/night arbitrage in electricity prices. […] Peak prices have fallen, which reduces the incentive to store electricity in the way it has been done [at night]." (interview 10-1, incumbent div. electrical/mechanical engineering firm)
- "The basic dilemma that we have when it comes to innovation [in energy storage and distributed energy] is that we don't know anything about the market. We looked at the market for energy storage, but it was hard for us to quantify the potential because we don't know how the market is going to develop. We cannot tell who the large players are, the four large energy suppliers or the regional level or even end customers […]." (interview 21-1, incumbent div. chemicals firm)
- "Energy storage such as power-to-gas or power-to-heat […] are things that work technologically, but commercially, esp. when it comes to regulation, there is still a lot to do." (interview 22-1, incumbent foc. municipal electricity supplier)
- "Since the declaration of Energiewende the entire topic area of smart grids, smart markets, and so on is becoming ever important. However, […] we are not doing that much more than before, because it is so complex and we don't really know what to develop. […] The framework conditions are still open." (interview 13-1, start-up foc. solar tech. firm)

Nevertheless, most market participants are wary of the installation of strong incentives to increase the deployment of energy storage such as feed-in tariffs for electricity out of storages and rather favor changes to the electricity market regulations that facilitate the installation and integration of storage facilities.

6.2.2 Adoption

The case studies show that Energiewende policies and other factors have had an impact on the adoption of knowledge and technology in Germany and hence contributed to the diffusion of more environmentally friendly technology. The analysis is structured along the most meaningful categories of such knowledge and technology that emerged during the case studies: renewable energy generation technology, energy-efficient technology and the electricity grid.

6.2.2.1 Expansion of generation portfolio to renewable energy

The case studies reveal to no surprise that the most noteworthy technological diffusion that occurred in the context of Energiewende was the widespread adoption of technology to generate electricity from renewable energy sources (RES-E). This adoption was fuelled especially by the attractive feed-in tariffs for RES-E installed by the 2000 Renewable Energy Sources Act (*EEG*). Although the German feed-in tariffs were directed at households and private investors rather than firms, electricity suppliers did incorporate RES technology in their generation portfolio over time.

In the 1990s ventures into renewable energy generation were single pilot projects for incumbent electricity suppliers, most importantly to demonstrate to the interested public that the topic was addressed at all, but not with a serious business interest behind it:

- "We discussed this very early, even in the 1990s when subsidies for solar technology only just started. But [RES technology] was rather belittled and dismissed as a short-lived trend. It took a long time for us to get interested. […] Of course we did a few tests, […] but this was rather for PR-reasons. Window dressing if you want to call it that." (interview 7-1, incumbent foc. national electricity supplier)
- "There were some activities [in the 1990s], but not sophisticated or strategic […], a test wind farm for example. […] We tried funny things. […] We did our business as usual and these new initiatives rather came from citizens and civil society." (interview 5-1, incumbent foc. municipal electricity supplier)

Incumbents in the electricity generation business had a hard time realizing the potential of renewable energy because financial returns were unattractive compared to what the industry was used to because the decentral generation that follows renewable energy was contrary to the established business logic which held that energy was most efficiently and hence best generated and distributed from large, central power plants.

- "As a business area [renewables] did not satisfy the rate of returns required by energy suppliers." (interview 5-1, incumbent foc. municipal electricity supplier)
- "We were not interested in the petty business of solar plants. This was just too contrary to our understanding of our business as an energy supplier. We had always been focused on large, central power generation plants." (interview 7-1, incumbent foc. national electricity supplier)

In the years following 2000 electricity suppliers began to add renewable energy capacity to their generation portfolios. The primary driver behind this was the installation of RES-E deployment schemes such as the EEG in Germany and other countries around 2000 which had turned these investments into a positive business case, although still relatively unattractive in terms of investment returns compared to large conventional power plants. At first the entry into RES-E occurred rather opportunistically to serve political and public opinion and was merely supported by the positive business case. However, over time the sporadic activities became more strategic as firms chose location as well as renewable technology based on where they could generate the highest return. Activities were also institutionalized in dedicated renewable energy business units tasked with the development of RES projects and the operation of the RES capacity.

- "Politics made us go into [renewables]. That is just *zeitgeist*. It was noticeable across parties and also in the general public." (interview 5-1, incumbent foc. municipal electricity supplier)
- "We started to acquire wind farms in [the mid 2000s]. Of course also because of and with the financial incentives, that made the business case. But climate change and global warming were important topics as well." (interview 7-1, incumbent foc. national electricity supplier)
- "EEG subsidies played a role for the business case." (interview 4-1, incumbent foc. municipal electricity supplier)

The ongoing improvement of RES-E technology that decreased investment costs and improved the performance and longevity of such technology moreover helped to convince electricity suppliers of renewables. Many technologies were moving towards electricity generation on an industrial level, which resembled the classic large-scale power generation much more than the beginnings of renewables with small solar PV installations or single wind turbines. Especially the emergence of offshore wind with large turbines of significant generation capacity and biomass where the electricity is produced through combustion just as in conventional power generation, were easy to comprehend and access for incumbent electricity suppliers. These technologies matched their perceived organizational capabilities and resources as well as existing business relations with customers and suppliers. Offshore wind due to its high technological and financial risks especially in the deep waters far from the shore was a business for the larger electricity suppliers, often acting in joint ventures. Biomass turned out to be attractive for municipal utilities as they could secure supply through their existing connections to local farmers i.e. producers of biomass. For many firms the pursuit of RES activities also meant expanding into new geographic markets. National as well as municipal suppliers moved into markets in other European countries, and sometimes even beyond Europe.

- "We needed some time to break out of our opposition against renewables. […] Hydro has of course always been our domain, biomass as well, but especially wind and solar were not taken seriously." (interview 6-2, incumbent foc. national electricity supplier)
- "It was only in the mid 2000s when offshore started to emerge that we got interested. That was something we understood: large plants that generate lots of electricity." (interview 7-1, incumbent foc. national electricity supplier).
- "[We have invested in biomass since 2003], but PV was never a topic for us […] because we would have taken the role of a sole financial investor. […] Biomass is closer to conventional generation. There is a supply chain. That means we can create value and contribute with our know-how." (interview 4-1, incumbent foc. municipal electricity supplier)
- "It was a radical step we took there. We were a very traditional, organically-grown supplier. And then we changed our strategy in the direction of renewable supply. […] And we went into the world." (interview 15-1, incumbent foc. municipal electricity supplier).

6.2.2.2 Energy-efficient modernization of generation portfolio and other assets

Next to renewable generation technology, fossil-fuel based electricity generation in conventional power plants remained a stronghold that incumbent electricity suppliers held on to throughout the 2000s. Conventional power plants remained the core of their business model and reliable cash cows at least when wholesale electricity prices were at comfortable levels until 2011 (cf. section 6.2.3.5.3).

In the mid 2000s several electricity suppliers started projects to update their conventional generation portfolio and even construct new, more energy efficient conventional power plants. The main motive for investing in conventional generation capacity while the energy transition was under way was that it still constituted an attractive investment case given the high electricity prices at the time. Furthermore, suppliers believed that conventional generation capacity would always be needed as reserve capacity and replacing technologically superseded power plants with the latest energy-efficient generation technology even provided an environmental rationale. Similar to the development of CCS technology (cf. 6.2.1.2), the price on carbon imposed by the EU emissions trading scheme (ETS) was an additional driver for the modernization of conventional generation capacity.

- "There was a trend towards more ownership of power generation assets. Many companies tried to build power plants […], especially coal-fired ones. We had similar plans." (interview 15-1, incumbent foc. municipal electricity supplier)
- "Until about 2008 it was our strategy to modernize our generation portfolio. New power plants, highly efficient power plants […] for a future with emissions trading, this seemed attractive at the time." (interview 3-1, incumbent foc. national electricity supplier)

In addition to power plants, also other production sites, commercial and residential buildings, and physical assets in general were reviewed and modernized in the mid 2000s in order to make them more energy-efficient. The reasons here were immediate cost reductions, energy efficiency standards, and partially public relations motives to promote own energy-efficient products by demonstrating their usage.

6.2.2.3 Modernization and expansion of electricity grids

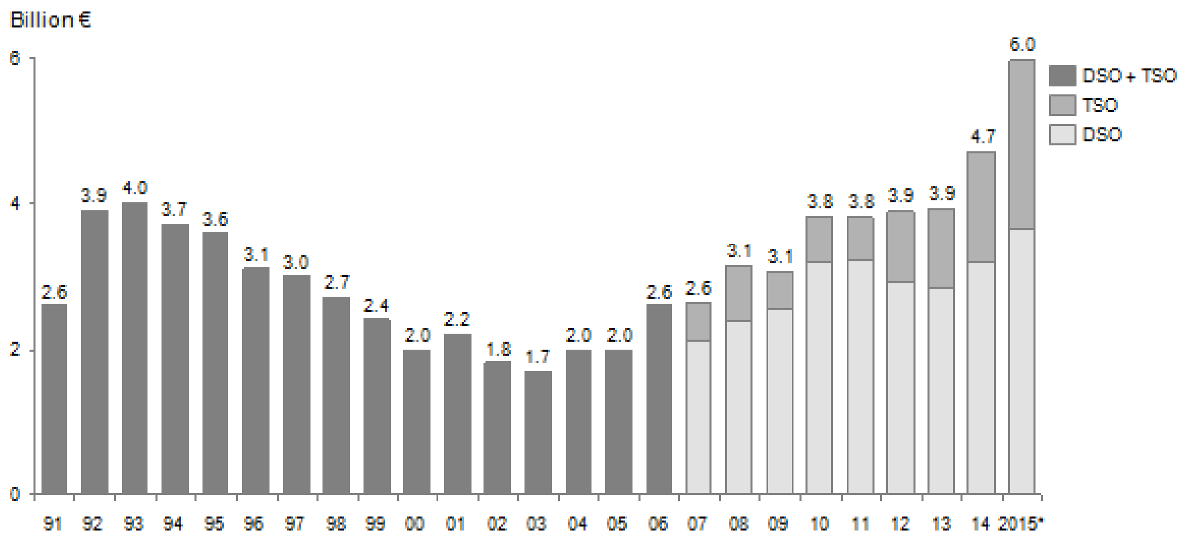
The adoption of new technology also occurred in the area of power grids. In Germany the electricity grid infrastructure is managed by two different players, transmission system operators (TSOs) and electricity suppliers that act as distribution system operators (DSOs). TSOs own and operate they high voltage transmission grid that transports electricity across regions. They were created in the course of the liberalization of electricity markets throughout the 2000s as the electricity value chain unbundled and transmission grids were carved out of electricity supply companies. Low voltage distribution grids are still owned and operated by the incumbent electricity suppliers. This can be either the large national ones or smaller, municipal ones.

Electricity transmission and distribution companies have heavily invested in modernizing and updating the physical and virtual infrastructure of their grid since the mid 2000s. Data on annual investment volumes by TSOs and DSOs shows a steady increase of investments in grid infrastructure since about 2005 with an additional boost after 2014 (cf. Figure 18).

The case studies show that these investments go into grid expansion, but also modernization and update of existing grid infrastructures: offshore wind parks are connected to the grid, long distance transmission lines extended, the distribution grid updated to cater to the needs of prosumers, and software installed that enables a more effective management of grid capacity. Through these investments new technologies that were not used previously are rolled-out and diffuse across the energy systems.

- "We are installing things that did not exist before, interconnectors [...], direct current transmission lines, [...] phase shifters - completely new types of assets." (interview 9-1, incumbent foc. TSO)

Figure 18: Annual investments in the electricity grid by TSOs and DSOs 1991-2015



*2015 data is planned

Sources: Own graphic with data from BDEW (2016) for years 1991-2006, Bundesnetzagentur (2014) for year 2007 and Bundesnetzagentur and Bundeskartellamt (2016) for years 2008-2015.

The main driver behind these investments is the mandate of grid operators to ensure the stability of the grid and with it the security of electricity supply. This is manifested in a series of laws and regulations. For TSOs especially the grid expansion plans and corresponding laws are relevant. The first such law (*Energieleitungsausbaugesetz*, EnLAG) was implemented in 2009, but subsequent changes and new laws especially following Fukushima increased the extent and pace of grid extension. As a consequence the investments of TSOs rose sharply in the years after 2011 (cf. Figure 18).

- "The grid expansion decision was only finalized after [the political decisions following Fukushima in 2011]. We invest [much more now]. (Interview 14-1, incumbent foc. transmission systems operator)

For DSOs, grid extension is guided by the legal requirement to connect end users of electricity to the electricity grid. Furthermore, the decentral installation of RES-E generation capacity imposes new requirements on the grids such as being able to take instead of just distribute electricity, which requires investment and updates.

- "There is a lot of work and investment due in the distribution grid. The majority of renewables feeds into the distribution grid, not the transmission grid. The role of the grid has changed completely." (interview 6-2, incumbent foc. national electricity supplier)

However, especially with regards to the distribution grid, the current regulatory framework may impede investment. As a network industry prone to natural monopoly almost every aspect of the TSO and DSO business is regulated. The German network industries regulator *Bundesnetzagentur* sets maximum permissible revenue for each TSO and DSO by adding a profit allowance to the average total costs of operating and maintaining the electricity grids. TSOs and DSOs have to set their grid usage fees i.e. the price component of their revenue in such a way that they do not exceed the maximum permissible revenue (Groebel, 2013). Since 2009 there is an additional incentive regulation to keep costs down. Grid operators are assessed on their relative efficiency in comparison to their peers and the maximum permissible revenue is set in such a way that inefficiencies must be eliminated in order to retain profitability. This is done for a regulatory period of five years instead of the previous annual cost regulation. In order to allow for investments, TSOs can apply for project-specific investment measures where, if approved, the investment volume can be added to the maximum permissible revenue hence justifying an increase in grid usage fees to cover the investment. DSOs can apply for a flat percentage increase to their maximum permissible revenue for every regulatory period (ibid.).

DSOs criticize that the current framework does not allow them to finance additional investments of a sufficient scale. This criticism has partially been taken up by regulators. An evaluation report published in 2015 finds that the incentive regulation has in principle succeeded in both increasing efficiency and securing investments, but that changes especially in the area of distribution grids are necessary in the light of Energiewende (Bundesnetzagentur, 2015). The changes pertain to improving payback rate and time and incentivizing investments into virtual grid capacity such as smart grids and grid management over physical expansion.

6.2.3 Organizational change

Changes to several organizational dimensions emerge as innovation activities from the case studies: corporate vision and strategy, structural organization change, cultural change, collaboration, and business models (cf. Figure 19).

Figure 19: Overview of dimensions of organizational change

6.2.3.1 Corporate vision and strategy

In the mid 2000s incumbent firms of both energy generation and transmission and energy technology and materials re-formulated their strategies, either the general corporate or more specifically their innovation strategies, in an effort to make their products and operations more environmentally-friendly. Drivers were perceived customer and market demand, as well as public opinion and shareholder activity.

The innovation and business development described in the previous sections was in some firms preceded by a distinct strategic decision to develop business in such a way. This was often the result of a deliberate strategy process that identified renewable energy and climate protection as important market drivers and therefore worth developing business in.

- "Our energy transition started to take shape in 2006/07. […] We […] developed a new strategy […] with renewable generation as one pillar. […] This was a radical shift […] for a […] traditional electricity supplier like us; […] renewable energy […] and [international expansion]." (interview 15-1, incumbent foc. municipal electricity supplier)
- "Our climate protection program [2007] […] was a strategic change with a view to the future, because so much change was happening around us in the energy system and the political landscape […]. The direction was towards climate protection, energy savings and CO_2 savings […] but as an economic actor […] one also needs to look at how to earn money […]." (interview 5-1, incumbent foc. municipal electricity supplier)
- "[…] Through our climate program [2007] we committed [significant] investment to research in climate innovation." (interview 26-1, incumbent div. chemicals firm)
- "[It was in 2005/2006 that we realized that] we need a solution for CO_2 emissions. And then it still took two years to enact this formally and organizationally" (interview 21-1, incumbent div. chemicals firm).

For others, the strategy rather emerged through the activities undertaken. Changes to the strategy esp. in light of market development such as changes to energy prices and the financial crisis were also not uncommon.

Realizing the strategic importance of environmental topics and the appeal that these topics have to customers and the wider public, diversified firms took a special effort to promote their environmental friendliness. They designated specific portfolios of their products that they marked green or environmentally friendly and in addition increased efforts to improve their products in such a way.

- "Our environmental strategy [of 2005] is an innovation strategy around sustainability in the widest sense […], primarily it is an abstract requirement to focus on particular products [or product characteristics]. […] The individual business units […] tried to shine […] in this competition. […] However, these aspirations took a back seat later, partly because of the financial crisis" (interview 10-1, incumbent div. electrical/mechanical engineering firm)

- "It was seen as a [business] opportunity […] to denote environmental and energy-friendly products as one portfolio. […] The elements that sustainability consists of [such as energy and resource efficiency] are also a selling point." (interview 2-1, incumbent div. electrical/mechanical engineering firm)

All companies surveyed had installed strategies, plans and targets that entail developing their product businesses as well as their own operations in an environmentally friendly and sustainable way.

6.2.3.2 Structural organizational change

The majority of companies surveyed in the case studies have enacted structural changes to their organization over the past one to two decades that are relevant in the context of Energiewende. These structural changes pertain to the overall corporate structure in terms of organization of business units as well as to the organization of innovation activities specifically.

Firms of all types across the energy technology value chain have created departments, business units or even separate firms to carry out business activities relevant in the context of Energiewende since the early 2000s. Many of the innovation activities described previously manifested themselves in organizational change in such a way. Examples of these are the organizational units for the renewable energy business that were set up by energy technology firms in the early 2000s and electricity suppliers in the mid- to late 2000s. In addition, formal organizations for energy efficiency also picked up in the mid- to late 2000s and business units around smart grid, energy management and energy have been emerging since 2010. The reason to formalize activities in these areas in terms of a structural organizational unit was the market and growth potential expected there and to increase the visibility of the respective products and services.

In addition to general business activities, firms restructured the organization of their Energiewende related innovation activities since 2010 in order to increase central control elevate their importance.

Incumbent firms in energy technology and materials, especially diversified ones who are not only active in the energy sector, created organizational departments specifically tasked with exploration, development and implementation of energy-related activities. These departments were often part of a larger R&D organization or put under direct supervision of a company executive. Often the scope extended from external to internal topics such as energy supply, usage and efficiency. Moreover, the energy was often combined with other sustainability and environmental topics.

- "We considered the topic sustainability so important [in 2010] that it should not be dispersed across the organization but occupy a central position. So we [addressed this with an organizational unit] made up of technology development and business development." (interview 20-1, incumbent div. electrical/mechanical engineering firm).
- "We put all energy-related topics central in [one] executive resort [in 2013]" (interview 26-1, incumbent div. chemicals firm)

Many firms in electricity supply and transmission centralized their innovation activities. Since innovation was for the longest time a low priority in the industry few had strong innovation organizations historically. For the large national suppliers it was common to have either a central R&D unit with few business links, or a range of activities spread across the firm without coordination. Innovation was hence running a risk of detachment from markets and business, double efforts or omission of important topics. Between 2010 and 2014 electricity suppliers enacted changes to the organization of their innovation activities. These changes included centralization with varying degrees of intensity, from simple central coordination and monitoring to steering and budgeting. Often an emphasis was also put on reorganizing activities in such a way that they are closer to markets and customers by structuring them along the value chain, linking central R&D functions with the operational business units depending on which unit will likely be the major beneficially and combining employees from all relevant areas in virtual teams. The motivation was to increase coordination of the activities and become faster in terms of developing and implementing relevant novelties.

- "[In our old organizational model] coordination was more of a coincidence." (interview 6-1, incumbent foc. national electricity supplier)

Across all firms restructuring and organizational separation was especially likely if the activities carried out were very new to the firm or addressed topics that were considered disruptive for the established business. Firms realized that the more distant an area of innovation is to current business, the less likely it is to be adequately addressed within the established organizational structures. Therefore innovation activities in entirely new areas, without prospects of generating revenue in the medium turn and very different to established business in terms of business logic, capabilities required or customers served were increasingly pursued by organizational entities separate from day-to-day business. The very innovation-oriented energy technology and materials firms took steps towards this already in the late 1990s and early 2000s by insulating such activities from the rest of the organization. This entailed creating an explicit budget for such innovation activities, establishing teams and departments exclusively focused on such innovation or even founding full-fledged, legally independent innovation subsidiaries. Among electricity suppliers this separation has only started to take hold with the innovation towards new business models after 2011 (cf. section 6.2.3.5).

6.2.3.3 Cultural change

The case studies also reveal that attempts have been undertaken to change corporate cultures as a response to coping with the changes of the energy system brought about by Energiewende. While cultural change has especially been in focus for electricity generation and transmission firms, also some incumbent energy technology and materials companies have described how they had sought a change of organizational culture in order to be able to effectively address the challenges of Energiewende.

Previous sections (cf. sections 6.2.1.1, 6.2.2.1) have mentioned the cognitive biases found across the incumbents of the energy technology value chain favoring an energy system based on conventional, central electricity generation. These biases were inscribed in the minds of individuals, echoed in formal and informal communications and manifested in the way that business was conducted. Attachment to an established way of doing things combined with the stability that the conventional energy system exerted over a long time created organizations with members who tended to be adverse to change and were not willing and able to imagine, let alone develop and implement innovations.

- "We knew that with our old business culture of securely operating large plants we were running into difficulties." (interview 3-1, incumbent foc. national electricity supplier)

- "The balanced, but also slow and even sedate manner that characterizes our firm, does not make things easier, especially now in an environment that is more dynamic […]." (interview 4-1, incumbent foc. municipal electricity supplier)
- "The energy industry has developed from a monopoly and is free of innovation. And that resonates in our organization and in the entire sector." (interview 4-1, incumbent foc. municipal electricity supplier)

This is why changes to the rate and direction of innovation activities, such as described earlier in this chapter, especially regarding renewable energy, a decentral energy system, and new business models, were accompanied by attempts to change the corporate culture towards becoming more innovative. In some firms the cultural change was a natural or evolutionary process that took place as a side effect of new strategies, business activities or technologies. In other firms, most noteworthy the large incumbent electricity suppliers, it was a deliberate attempt that was reinforced by the same margin decline after 2011 that triggered the search for new business models (cf. 6.2.3.5).

- "We realized [in 2012] that it is not only costs and balance sheet, but also the corporate culture that is not healthy in our firm. So we started a transformation on the hard facts as well as on the soft facts side." (interview 3-2, incumbent foc. national electricity supplier)

The ambition was to create a corporate culture that is more entrepreneurial i.e. where new ideas are encouraged, trying things out is supported, and failures valued as a learning opportunity. Furthermore, customer orientation and openness towards partnerships were supposed to be engrained in the organizations as they were both considered key for the new business models in the future energy system (cf. also sections 6.2.3.5 and 6.2.3.4).

- "Our CEO wanted […] to establish a new innovation culture where we experiment, even with existing things." (interview 3-1, incumbent foc. national electricity supplier)
- "We asked ourselves, how we get the innovative culture of a start-up firm. Fast actions, rapid prototyping, stopping things if necessary." (interview 3-2, incumbent foc. national electricity supplier)
- "Creating an internal culture with which we are able to react quicker to changing framework conditions, seek to innovate even small aspects, and be

more customer-oriented – that is the cultural change that we need to achieve." (interview 3-1, incumbent foc. national electricity supplier)

- "We need partnerships, […] even in minority stakes. This is new for electricity suppliers; it was unthinkable in the past." (interview 22-1, incumbent foc. municipal electricity supplier)

The affected firms used various methods to achieve this. Electricity suppliers, especially the larger ones, developed special programs, event formats and communications to incite an entrepreneurial culture. Open innovation sessions, interactive panels and talks were supposed to bring everybody to the table and encourage active participation in the innovation and change process. Innovation days and innovation competitions provided employees with the opportunity to develop their own entrepreneurial ventures and compete for acknowledgement and, sometimes, funds. Network structures and the staffing of innovation project teams from various departments pooled human resources and facilitated knowledge exchange. Leadership programs enabled managers to encourage curiosity and innovativeness in their employees.

- "We have several big cultural change programs ongoing. They involve the top management and all other management levels. This is an innovation […]. It is cultural change management […] with concrete actions." (interview 3-1, incumbent foc. national electricity supplier)

The interviewees have mainly painted a positive picture of this change claiming it is successful in changing corporate culture and that initial resistance faded over time.

- "It is a clash. Some love it, some hate it. It is definitely creating a stir." (interview 3-1, incumbent foc. national electricity supplier)
- "[Cultural change] is the hard part. Much harder than developing business models." (interview 3-2, incumbent foc. national electricity supplier)
- "You need to be patient. There is a lot of resistance in the beginning. […] But now after two to three years we are starting to speak the same language, do things differently, know what our mental barriers are so that we can address them." (interview 3-2, incumbent foc. national electricity supplier)
- "We did a couple of things that really hit, an innovation day, for example. […] Some departments got really creative. […] It worked." (interview 9-1, incumbent foc. TSO)

Albeit to a smaller extent than in electricity generation and transmission, also in energy technology and materials, cultural change was required to some degree as technological change took place. However, organizational restructuring and increasing the importance and visibility of the affected departments as described in the previous section (6.2.3.2) was by most interviewees considered sufficient to enact such change. Interestingly, some R&D or innovation departments consider themselves responsible for bringing about cultural change along with technological. One central R&D department of a corporate firm even described an internal consulting service specifically for change management.

6.2.3.4 Collaboration

The case studies show that collaboration has gained importance in the context of Energiewende. Collaborations affect every step of the innovation value chain from early idea generation and concept development to joint R&D, demonstration and marketing of products. Financially and organizationally they can take various forms e.g., informal exchanges (networks, groups), contractual arrangements (joint projects), the acquisition of equity in a partner firm (venture capital), or the foundation of legally separate organizations (joint ventures).

As one area of collaboration, vertical relationships between firms along the energy technology value chain have been strengthened. As explained earlier (section 5.3), there is an established division of labor in the energy technology chain anyway whereby technology is provided by energy technology firms and purchased and used by electricity suppliers. As such both types of firms cooperate especially in test, demonstration and pilot projects in the late invention and early commercialization stages of a new technology. Cooperation with customers seems to become more important at every step of the value chain. Even electricity suppliers are looking at their customers for sources of innovation.

- "Partners are now mainly downstream." (interview 6-1, incumbent foc. national electricity supplier)
- "You need alliances along the value chain […] especially in early phases or emerging markets." (interview 24-1, incumbent div. chemicals firm)

In addition to vertical relations, collaboration occurs increasingly between firms of the energy technology value chain and firms of sectors outside of it. Collaboration is especially sought where capabilities, assets or product and service offerings are considered complementary. Examples of such collaboration can be found e.g., between electricity suppliers and automotive firms in e-mobility and between electricity suppliers and natural gas firms in power-to-gas energy storage and fuels.

Collaboration also takes place across different market positions i.e. among incumbents or between incumbents and startups. Due to antitrust concerns collaboration among incumbents of different sectors is more frequent than among incumbents of the same sector. The latter may, however, still take place in ventures that are particularly risky and where boundaries can be well defined. Collaboration between incumbents and startups can take place in the same sector or across sectors. Incumbents rely on start-ups for fresh ideas and possibly intellectual property and knowledge of emerging technologies, while start-ups benefit from the strong financial position, market access and industry knowledge of incumbents. Startup-incumbent collaboration is especially important in all topics concerned with IT, digitalization and big data.

- "There are hardware partner, but also IT and software - this was not the case in the past. […] Many small firms, few global players." (interview 6-1, incumbent foc. national electricity supplier)

There are multiple reasons for the surge of collaboration in the context of Energiewende. First and foremost, collaboration is sought to pool complementary capabilities and assets in a way that enables the partners to be successful in a more complex energy system. The perceived increase in complexity is mainly attributed to decentralization and the shift to renewable energy. In addition, the advance of digital technology that is penetrating the energy sector also contributes towards perceived complexity. It is here where incumbent firms of all value chain steps fall short of the necessary knowledge and skills to be successful on their own and hence often have to rely on partners. As a related point, collaboration of course also means that technological and financial risks and burdens are shared.

- "Complexity [in the changing energy system] is increasing every day and you cannot master every aspect of it. You need good partners." (interview 17-1, start-up foc. national electricity supplier)
- "We are in areas that are at the edge of our established and successful business activities, where we do not typically have the competences, or only partially. In these areas we make faster progress with partners and reach a better substantive result." (interview 20-1, incumbent div. electrical/mechanical engineering firm)
- "[Cooperation] is all about the capabilities that we require. […] It is critical to success." (interview 22-1, incumbent foc. municipal electricity supplier)

- "If IT is the key [future success] factor we need the relevant expertise." (interview 4-1, incumbent foc. municipal electricity supplier)

Second, collaborations in the form of consortia are a precondition for many publicly funded research projects. The funding available for energy projects usually requires groups of players such as firms from different industries, universities and research institutes to work together on a specific topic. This provides a financial incentive for collaboration, but also the opportunity to build a network especially in new and emerging technological areas. However, the costs of coordinating and transacting especially in large consortia are considered very high, which is why firms are skeptical of their efficacy and some.

Third, collaborations provide an opportunity to experiment in a setting that is somewhat separate from the rest of the organization. Collaborations may provide a space shielded from established business processes and rules that may impeded innovation, which is very similar to the tendency to separate the organizational unit that is tasked with disruptive innovations described earlier (cf. section 6.2.3.2).

6.2.3.5 Business models

The case studies show that firms across the energy technology value chain, most prominently electricity suppliers, are trying to invent and implement new business models. To re-cap, a business model lays out how a firm generates and captures value with its strategy, structure and activities incl. value proposition, target market, set-up of the value chain, revenue mechanisms and cost structures, position in the value network and competitive strategy (Chesbrough & Rosenbloom, 2002).

6.2.3.5.1 *Asset-light green electricity marketing*

The first wave of exploring, developing and implementing new business models in the energy technology value chain took place in 1998/1999 when start-up electricity suppliers began to market electricity without owning power generation assets or transmission and distribution grids. This was made possible by the liberalization of the electricity markets which was just taking place. In addition, the electricity supply start-ups surveyed for the case studies were all focused on electricity from RES and claim to have been driven by an intrinsic motivation to supply green and clean electricity as well. In terms of business models, this marked a significant departure from the way that the electricity industry had worked in the preceding decades.

The traditional business model in electricity generation and transmission builds on the ownership and operation of power generation assets and grid infrastructure. In this business model the electricity supplied to customers was considered a commodity i.e. a unitary product that can due to its physical properties not be differentiated. As a consequence sales and marketing were considered of relatively minor importance. The start-up electricity suppliers, however, saw an opportunity for product differentiation, not through changing the product that is delivered to customers, but through changing the supply chain and, most importantly, the packaging and marketing of the product to customers:

"It was our first innovation to consistently exploit the provisions offered by the [liberalized] regulatory framework. Because of the liberalization of electricity markets we were able to supply electricity to residential customers." (interview 18-1, start-up foc. national electricity supplier)

Electricity was made into a differentiated product, at least from a marketing perspective, by offering customers tariffs for guaranteed GHG and nuclear free electricity:

- "We wanted to found an energy supplier who does the right thing ecologically." (interview 17-1, start-up foc. national electricity supplier)

They procured the required electricity through the trading opportunities offered by liberalized energy markets and electricity exchanges, thereby increasing the share of electricity from RES in the national electricity mix without operating power plants and generating the electricity themselves:

- "The EEG essentially led to investments in [RES] generation capacity […] However, for an energy service firm [such as an electricity supplier], there was no role there in that sense […] The German regulatory system does not provide for electricity generated in proprietary power plants to be directly supplied to end customers." (interview 18-1, start-up foc. national electricity supplier)

These new electricity suppliers realized that there was demand and a willingness to pay for certified green electricity and created a business model out of that. Interesting enough, even though they started with a new business model, some start-ups tried to replicate the traditional value chain in the industry and clung to the idea of owning generation capacity:

- "Investing in RES-E generation capacity has been part of our strategy from the start. The green energy industry has long lived with the conviction that the energy transition works best if customers buy green electricity from companies that own and operate the RES-E production facilities themselves. However, we have meanwhile departed from that." (interview 17-1, start-up foc. national electricity supplier).

Given the feed in tariff for electricity from RES was always higher than the market price of electricity, it would not have been economical (probably also not feasible from a regulatory point of view) to bypass that mechanism and supply electricity directly. It was hence deployment policies such as the EEG that incentivized RES-E capacity additions, not green electricity tariffs. However, the opportunities offered by electricity market liberalization coupled with an emerging market demand for GHG and nuclear electricity and an intrinsic motivation to provide such green electricity were the major drivers of this first wave of new energy industry business models.

6.2.3.5.2 *Complementary energy services*

Also incumbent electricity suppliers experimented with new business models when they developed energy service offerings in the early 2000s. When the industry was consolidating through mergers and acquisitions after the turmoil of liberalization, players were re-positioning themselves in the industry and experimented with new business models beyond the provision of electricity. Energy services that have previously already been described (cf. section 6.2.1.4.2) such as contracting, providing access to traded markets for electricity and other commodities especially after the EEG 2012 direct marketing provision, as well as energy efficiency consulting services serve as examples. These were the first attempts to establish new business models, although these were meant to extend and support the core business of electricity provision rather than replace it.

6.2.3.5.3 *Digital and big data business model experimentation post 2011*

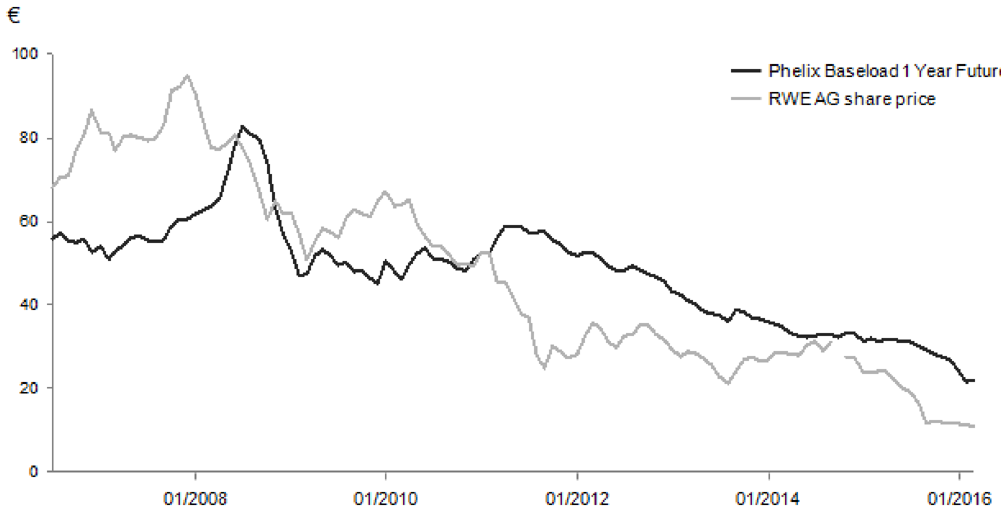
Since 2011 electricity suppliers, especially incumbent ones, have been exploring, developing and partially already implementing new business models especially in the context of digitalization and big data. This is a response to the price decline that has occurred in the wholesale electricity markets and an exploitation of the new opportunities offered by technological progress in information and communications technology. Energiewende and the concomitant transformation of the energy system is now a credible scenario with a firm political commitment and since it does not seem to be possible to make a profit with the traditional business model alternative ones need to be found.

In spite of all developments in the energy system, the traditional business model of energy generation incumbents – generating electricity in central power plants and distributing it to customers – did for a long time remain unchallenged. Electricity generation companies just operated RES-E capacity in the same way that they operated their conventional power plants and added green electricity tariffs to their customer product offering. The focus of corporate activities remained in the upstream part of the firm, the generation business.

However, this changed when the conventionally fuelled power plants that the incumbents relied on for much of their revenue came under pressure due to falling wholesale electricity prices since 2011. The price of an electricity contract for delivery one year in the future dropped from all time highs around 80€ in 2008 to below 30€ in 2015, staying consistently below 50€ since 2011 (cf. Figure 20).

. Owners and operators of power plants earn their revenue based on the money they get for electricity generated which they sell on the spot market or future markets. In the existing design of the German electricity market the price is determined only based on the energy generated i.e. compensation occurs per megawatt hour (MWh) generated and sold. The market price is set by the marginal production costs of the last power plant that is able to sell its electricity output at a given level of demand. The increasing generation of electricity from RES changed the economics for conventional power plants significantly. The generation of RES electricity at zero marginal cost coupled with the rule that all RES electricity volumes need to be sold on the market caused wholesale electricity prices to drop significantly and forced higher cost power plants to make losses. This phenomenon is also called merit order effect (Sensfuß et al., 2008).

Figure 20: Performance of Phelix Base Load One Year Futures and RWE AG



Sources: Own calculations based on EEX and DAX electricity and share price data provided by finanzen.net (2016a, 2016b).

The huge losses incurred in conventional energy generation are the primary driving force behind the search for new business models:

- "Our motivation is the margin decline […] that is caused by [RES capacity] growth and oversupply of electricity […]. We were faced with the choice to reduce our business activities as many municipal electricity suppliers have done. But we decided […] to grow and substitute new business for our profit gap." (interview 22-1, incumbent foc. municipal electricity supplier).
- "The question is, how do we deal with the mess that we are in. […] It is impossible to say what will happen in conventional generation. That is a question of market design, a political question. […] We have to look for new business models. Although we know that it is hard to compensate for our losses, we still need to renew ourselves and expand. Our [business] will become smaller in scale. No large physical infrastructure […], but small investments, close to the customer. […] And decentral electricity supply [with off-grid elements] would erode our business model even further." (interview 3-1, incumbent foc. national electricity supplier)

While emergency cost reduction measures were implemented immediately following the drop in electricity prices and the post-Fukushima political decisions in 2011, it is since 2013/2014 that incumbent electricity suppliers look ahead again and direct their efforts on finding new business models i.e. changing their traditional value chain, the products they provide and the way they are provided, in an effort to not have to rely on revenue from electricity generation:

- "To develop business models for a decentral world, that is [our] strategic direction. We believe that the future energy system will look differently. […] [And for us], it's all about earning money." (interview 3-2, incumbent foc. national electricity supplier)
- "We know […] that we are not going to find a cash cow [like the one we had] in the previous 140 years." (interview 22-2, municipal electricity supplier)

Many firms have to this end set up dedicated organizational units and teams specifically tasked with business model innovation. They also go new ways when it comes to the implementation of novelties e.g., co-operation with start-ups, partnerships with minority stakes or altogether outside of established business boundaries.

- "[When we have developed a good concept and substantiated it] it goes to Sales. That can mean our Sales, but it does not need to. […] It really does not matter under which brand something is marketed" (interview 22-2, municipal electricity supplier).

However, also firms not under direct revenue and cost pressure such as the electricity supply start-ups or players from the upstream part of the value chain and other sectors have been working on new business models in the electricity industry since about 2010. Incumbent electricity suppliers acknowledge this increasing competition from new players: "We have found in recent years […] that firms are entering our market who are not competitors in the classical sense. Telecommunication firms, electrical engineering companies, start-ups and other small innovative firms. […] These firms built on our value chain and have ideas for new business models in our market" (interview 3-2, incumbent foc. national electricity supplier). Although these firms do not have the same liabilities and immediate margin squeezes as pressures to act, they are still trying to shape how the energy system will look like and what business models may work:

- "We are thinking about innovative business models, just as every electricity supplier does right now" (interview 17-1, start-up foc. national electricity supplier).
- "We don't […] know what is gonna be possible, where we can invest, what business models will work" (interview 13-1, start-up foc. solar tech. firm).

- "We are thinking much more in terms of business model innovation than we used to do" (interview 2-2, incumbent div. electrical/mechanical engineering firm)

In substantive terms, the new business models of all types of firms are targeted at ways to earn money in an energy system that is decentral, albeit nobody knows how exactly that system will look like. Common assumptions include that the generation as well as the consumption of electricity will be distributed geographically, that the system tends to be nuclear and GHG emission free and that it is able to cope with volatility and the fluctuation of supply that seems to be a consequence of the generation of electricity from RES. New business models that are being experimented with revolve around creating new functions in the energy system that do not exist right now, providing services to transmission system operators and providing additional services to consumers and prosumers of electricity. The regulatory framework that governs the energy system and the changes that are anticipated to take place because of Energiewende policies hence provide the boundary conditions in which the search for a new business model takes place.

Moreover, the technological progress in information and communication technologies constitute the search space in which opportunities for new business models are expected to be found. Digitalization, big data and internet of things are keywords that were frequently employed when interviewees described the direction of their search for a new business model. In terms of the value chain, electricity suppliers have moved their focus from upstream generation to the downstream business now looking to invent and implement solutions for customers.

- "We looked at what other electricity suppliers [and tech companies] are working on and quickly got to the topics big data, data analytics, […] disruptive digitalization, […] internet of things and smart and connected home – how will management and optimization work in a decentral energy world." (interview 3-1, incumbent foc. national electricity supplier)
- "[Nuclear and coal are gone], but we still have the market with end customers that has come back into focus." (interview 6-2, incumbent foc. national electricity supplier)
- "It is about customer orientation, almost with brute force." (interview 22-1, incumbent foc. municipal electricity supplier)

6.2.4 Synopsis: change dynamics in innovation activities

This section has investigated the change dynamics of the German Energiewende, specifically to what extent and how German firms changed their innovation activities over time. It was divided into three innovation activities: exploration, development and implementation, adoption, and organizational change. The findings show that different dynamics can be found in each of these innovation activities as the focus of activities and the intensity with which they were pursed changed over time and indicate that the drivers of such activities are multiple, complex and intertwined.

Exploration, development and implementation were noted in several technology areas, more specifically renewable energy generation and supply, conventional energy generation and supply, energy consumption and efficiency, smart grid and energy management, and energy storage. For renewable energy generation and supply the case studies identify the emergence of exploration and development activities in the 1970s to 1990s. Early developments were marked by technological experimentation in order to find alternative energy sources. This development was triggered by the risk to the energy supply posed by the oil crises of the 1970s, a rising environmental awareness of the wider public and the installation of public funding for energy research. Renewable energy technology, however, stayed a niche throughout the 1980s and 1990s as market demand was low and mainly small firms invested in technological development. This changed in the late 1990s and especially after 2000 when the development of RES-E technology surged as a consequence of the RES-E deployment policies that were implemented in Germany and other countries. Demand growth and the emergence of a sizable market reignited the interest in RES-E technology. Large incumbent energy technology firms, however, struggled to build their activities in RES technology as they perceived their existing assets and capabilities not to be complementary to the requirements of RES technologies. Not the technological exploration per se was the problem, but rather the implementation in terms of going to market with an industry and customer structure that they were not used to or did not possess. In addition, the view that RES technologies were inherently inferior to conventional technology was also widespread and prevented openness towards new developments. Those challenges had several portfolio restructurings and attempts and failures as a consequence. Ultimately, however, also large firms began to invest and together with fast growing energy technology start-ups accelerated the development of RES technology towards industrial scale. With the maturing of growth in

RES-E installations it became an area of steady activity with a sizable and still growing market.

The exploration, development and implementation of ways to cut the energy consumption of products and processes followed a similar path, however, less pronounced. Driven largely by cost considerations the interest in energy efficiency fluctuated with expectations of energy prices and consequential customer demand for higher energy efficiency. There has been an increased focus since the mid 2000s against the background of political targets, stricter standards for energy consumption, and public concerns about climate change. At the same time energy efficiency also emerged as a services business. Non-emitting conventional technology topic became a focus topic for exploration in the mid 2000s, but interest, at least in Germany, has declined since.

In the late 2000s the focus of exploration, development and implementation activities shifted from electricity generation and consumption towards more systemic topics in response to the challenges posed by a changing energy system and the demand for systemic solutions. A rising share of fluctuating RES-E in the electricity mix, geographically distributed generation capacity and a blurred distinction between consumers and producers of electricity challenged to the electricity grid network. The exploration of technology to improve the grid infrastructure, manage the electricity fed in or taken out of the grid with supply and demand side energy management, as well as various solutions to storing electricity took center stage.

In terms of adoption, activities took place in the expansion of electricity generation portfolios to renewable energy, energy efficient modernization of generation portfolios, and modernization and expansion of electricity grids. After experimental installations in earlier decades, electricity suppliers started to add RES-E capacity to their generation portfolios after 2000, mainly driven by a combination of public and political pressure and the subsidized compensation of the EEG feed-in tariff. For incumbent electricity suppliers the uptake of RES-E was, however, impeded by the protection of their strong portfolios of conventional electricity generation capacity and an inherent belief in the superiority of conventional generation, especially in terms of efficiency and reliability. In an effort to address the emerging environmental requirements, energy-efficient modernizations of the energy generation portfolio as well as other assets took place. The expectation of higher energy prices also played a role in these efforts. Since the mid 2000s electricity suppliers and transmission firms increasingly invested in the modernization and expansion of the electricity grid network to cope with the rising amount of RES-E that had to be taken up and funneled through the system.

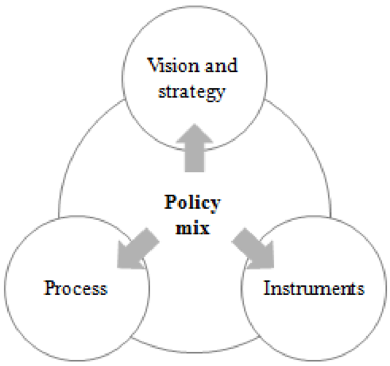
Organizational change was identified with respect to corporate vision and strategy, structural organizational change, cultural change, collaboration, and business models. In the mid 2000s incumbent firms began to increasingly incorporate environmental elements in their corporate visions and strategies. Structural organizational change started to manifest itself as well. New business units or departments for Energiewende-related activities such as renewable energy or energy efficiency were established and the respective innovation activities often placed in separate entities and under supervision of the senior leadership. Cultural change came alongside structural change either naturally or, especially for large electricity suppliers after 2011, as dedicated programs to make their organizations ready for a new energy system. Overcoming the aforementioned biases and preconceptions was the key subject of cultural change programs. Organizational change was marked by a growing importance of collaborations. With systemic changes, but also other developments such as digitalization, firms increasingly had to rely on the complementary assets and capabilities of strong partners in order to succeed in novel activities. Business model innovation constituted another significant area of organizational change. New business models such as asset-light green electricity marketing and the provision of services in general emerged since the late 1990s because of liberalization and since the late 2000s because of digitalization and the systemic change in the energy system. This development was compounded by the political decisions and market developments following the Fukushima nuclear accident in 2011. Fukushima in general strengthened innovation activities as Energiewende finally became a consensus after decades of political debate, but the traditional business model of electricity suppliers was specifically affected. The decline of the wholesale electricity price that took place after 2011 put a final stop to the traditional business model of large scale conventional electricity generation and forced incumbents to intensify their search for new business models.

Across all three innovation activities it is particularly noteworthy that it was seldomly one driver that triggered a particular dynamic, but typically a combination of variables. Aspects of the Energiewende policy mix such as the long-term RES and emission reduction targets, public R&D funds, the effects of the RES-E feed-in tariff and standards clearly played a role, but so did market factors such as supply, demand and prices, as well as wider societal trends such as public opinion and digitalization. Over time these variables came together in a web of influencing factors where the effect of one cannot easily be singled out. In addition the findings suggest that interpretations of external events were confounded by firm-internal factors such as assets and capabilities, a firm's business model and a cognitive representation of how an energy system should best be set up. Following the presentation of the general development of innovation activities and innovation dynamics as it emerged from the case studies, the following chapter will discuss the drivers and influences of these dynamics in more detail.

6.3 Impact of the Energiewende policy mix

Having established that changes in innovation activities have taken place, the attention now turns to carving out in more detail how the Energiewende policy mix and its individual components vision and strategy, instruments, and process have affected these changes. All aspects discussed here as parts of the policy mix were noticed by companies and factors taken into consideration in their innovation activity. In many cases the political influence was indirect i.e. it only played out over time, via another mechanism and together with other influencing factors. However, certain political interventions were decisive in way that they significantly determined the innovation dynamics in the energy technology value chain.

Figure 21: Overview of elements of the policy mix



6.3.1 Vision and strategy

The case studies show that the political vision and strategy devised by the German government as part of Energiewende did have an impact on corporate innovation activities, but only to a limited extent. The limited effects stem predominantly from the fact that vision and strategies are not practical enough to result in immediate corporate action. Vision and strategy expressed in long term targets, plans and roadmaps are critical points of reference important to a stable policy framework, but they are not in themselves sufficient to drive innovation activities if other conditions (most importantly market demand) are not in place. In the context of Energiewende, three manifestations of the German political vision and strategy have been noted by companies as having had an impact on their actions; the first nuclear exit of 2000, long term targets regarding greenhouse gas (GHG) emissions, renewables and energy efficiency, and the political decisions for accelerated nuclear exit following the Fukushima nuclear disaster in 2011.

The nuclear exit decision of 2000 was duly noted, but did not trigger immediate action in terms of innovation activities, mainly because it was not sufficiently credible. Electricity suppliers tended to not take it serious and were confident that they would be able to lobby a milder version eventually. Even if they did believe that change was going to happen, it was in a future too distant to be relevant for corporate actions at the time. Energy technology and materials firms were also only marginally affected. Those with activities in the nuclear industry anticipated a market decline, but not a significant one since their activities were mostly global and the German nuclear capacity only constitutes a small fraction of the global one.

- My impression was that the energy industry did not take the earlier nuclear exit decision of [2000] very seriously. [...] The large electricity suppliers pushed the first exit aside. " (interview 2-2, incumbent div. electrical/mechanical engineering firm)
- "The year 2000/2001 when the nuclear exit treaty was signed, that was a first turn. It was considered visionary – but also in the sense that, it is going to happen sometime in the very distant future." (interview 3-1, incumbent foc. national electricity supplier)

The long term targets that were formulated in the course of the energy transition constituted important points of reference that firms used to understand and predict the future of the energy sector, but they did not have an immediate effect on corporate actions. The case studies show that firms use long term targets to make better predictions of the future development of their relevant markets. They are typically employed as a basis for scenario analyses and forecasts. The case studies reveal that firms' assessment of market potential was decisive for innovation activities. Long term targets underpin future market potential and nudge innovation activities, especially exploration, development and implementation, in a certain direction. Credible long term targets hence provide guidance and direction, but are trumped by current laws, regulations and economic incentives when it comes to making short-term decisions. Targets are supported and made more credible by roadmap or plans for their implementation.

- "Of course we consider [political targets in market forecasts and scenarios]. However, I claim that they are not very influential for today's strategic decisions. [...] We use them as an argument for entries into [new business areas], but they are too long term to use them as a basis for decision-making." (interview 2-1, incumbent div. electrical/mechanical engineering firm)
- "They guide our actions to a certain extent, because they are an expression of political will and public sentiment. [...] They codify an implicit agreement." (interview 6-1, incumbent foc. national electricity supplier)
- "The *BMU Leitstudie* [that described scenarios for the development of renewable energy] and was in place until 2012 always guided our actions. [...] We did consider this sufficiently reliable, especially together with the 2010 Energy Concept and the 2001 Meseberg Decisions [implementing EU decisions for an integrated energy and climate program]" (interview 4-1, incumbent foc. municipal electricity supplier)

Of the various long term targets that have been defined in the course of the energy transition, not all targets are equally important to all firms. Long term targets exist in various polities (Germany, EU, international) and for various areas such as greenhouse gas emission reductions, the deployment of renewable energy sources, energy efficiency or e-mobility. Of all the political long term targets defined over time, only the German 2010 Energy Concept and the EU targets for 2020 and 2030, which do not belong to the Energiewende policy mix, were specifically mentioned by interviewees[1]. Firms pay attention to targets set in markets where they are active in.

The importance that firms attribute to targets depends on their areas of activities and market reach, as well as credibility of the targets. GHG emission reduction targets tended to be more important for industries who are large emitters, such as the chemical firms and the electricity suppliers surveyed. Targets pertaining to RES deployment were closely monitored by electricity suppliers and TSOs, and to a smaller extent by energy technology firms. Energy

[1] This might, however, be the case because they are the most recent ones and the ones relevant now.

efficiency targets were particularly important to energy technology and materials firms. As targets go into market forecasts, they are weighed by the relative importance of the market to a particular firm. For firms active on a global market, such as most of the energy technology and materials companies surveyed, German targets by themselves only as important as the German market to their global activities. For firms with the bulk of their activities in Germany, such as energy generation and transmission companies, the German targets were the most important ones.

The political decision to accelerate the nuclear exit following Fukushima increased the change dynamics across all sectors in the energy technology value chain.

- "Everything got more dynamic after 2011." (interview 8-1, incumbent foc. heating tech firm)
- "I have the impression that [after Fukushima] it was easier to get internal funding for [Energiewende relevant] R&D projects. But we did not start an entirely new program for energy transition research." (interview 26-1, incumbent div. chemicals firm)
- "[With the political decisions after Fukushima] the energy transition became political mainstream." (interview 27-1, start-up foc. solar tech. firm)

For energy technology and materials firms as well as TSOs, it did not have a fundamental impact on the direction of innovation activities as the strategic direction had mostly been set before and consequently all innovation activities were started and ongoing.

- "Fukushima did not lead to substantial changes. Our direction towards sustainability had been set earlier." (interview 21-1, incumbent div. chemicals firm)
- "Our decisions and investments are long term, single situations do not result in massive changes." (interview 19-1, start-up foc. solar tech. firm)
- "[Dynamics did not change after 2011] because we are not working for private customers, only commercial and industrial ones. And that is a business driven by economics." (interview 26-1, incumbent div. chemicals firm)

For electricity suppliers, the situation got worse after the accelerated nuclear exit as the value of their nuclear assets dropped significantly over night and firm value decreased as a consequence. However, the strong push towards business model innovation which started after 2011 and has been described earlier (cf. section 6.2.3.5) was not only driven by these devaluations, but there was an overlapping effect of falling electricity prices which occurred as a consequence of rising RES electricity volumes. Hence, it was not only the new post-Fukushima political vision and strategy that initiated the changes in innovation activities of electricity suppliers, but rather the market price effects that are the result of other political interventions, such as the Renewable Energy Act, which is further elaborated below (cf. section 6.3.2.2).

- "Fukushima and the political turnaround made it obvious that problems [for the energy industry] are getting worse. [...] It was the last straw. We had structural inefficiencies historically, but were able to afford them in the past, but over the time less so, and Fukushima finally pulled the plug." (interview 6-1, incumbent foc. national electricity supplier)

One interviewee even argued that the turnaround of Fukushima damaged innovation activity as electricity suppliers became financially unstable and were hence not able to continue investments at the same rate as before. This might have affected their own innovation activities as well as those of their suppliers, mainly energy technology firms, whose potential market decreased with decreasing financial capacities of their customers. Views on this, however, varied and remain inconclusive.

Similar findings regarding the effect of vision and strategy on innovation activities have been presented in earlier empirical research in environmental economics and innovation studies. For example, conducting research on the innovation effect of the European Emissions Trading Scheme (EU ETS) several scholars have found that long term targets regarding climate protection and greenhouse gas emissions had a positive effect on innovation activities (Rogge, Schneider, et al., 2011; T. S. Schmidt et al., 2012). Political environmental targets serve as market information that provide a cue to the long term development of a particular sector and as a consequence encourage innovation activities relevant to the environmental target in that sector (ibid.).

6.3.2 Instruments

6.3.2.1 Technology-push instruments

The case studies show that technology-push instruments i.e. direct financial support for research and development (R&D) has been widely used and that they motivate innovation in the respect that the financial risks of R&D investments are decreased. Technology-push instruments are very effective at early stages of technological development and to foster technological progress that requires the combined strengths of various actors, i.e. firms from different industries and value chain positions with universities and public research institutes. However, in addition to some procedural downsides they cannot create markets and hence provide for sustainability of the investments in technological development.

All but one of the case study participants confirmed that their firm take or have taken public R&D funds. The main motive for using public funds is to share and hence decrease the financial risks of technological development. Public research programs were instrumental especially for the early technological development of RES technology. The origin of today's wind and solar technology firms often lies in universities and publically-funded research projects of the 1970s to 1990s.

- "The development of renewable energy is closely linked to public research funding. The evaluation of the last Energy Research Program of the German federal government found out that, in contrast to other technologies, research funding in renewables was very successful in making academic research results into products [...]. An important pillar there is personnel transfer; academic research is where the R&D staff of the renewables industry learnt their skills." (interview 13-1, start-up foc. solar tech. firm)
- "We are looking at all topics from a global perspective and public funds are important, especially when it comes to high risk topics." (interview 24-1, incumbent div. chemicals firm)

In addition to risk reduction, building a network and partnerships for research collaboration were mentioned as the second important reason to use public funds. Most public research programs require the collaboration of many actors in a consortium in order to be eligible for funding. Such collaboration increases knowledge sharing and facilitates the development of products that require interfaces with other products or systemic elements.

- "Publically funded projects provide the opportunity to immediately build a network, especially in areas without much prior experience." (interview 20-1, incumbent div. electrical/mechanical engineering firm)
- "One industry in the energy sector cannot master these big challenges by itself. You need alliances [...] When it comes to new areas you always need the trio of academia, industry and politics. [...] Public research funding is in our view an important instrument to align interests and push developments [in partnerships]." (interview 24-1, incumbent div. chemicals firm)

In terms of the specific programs, the case studies did not fully reveal which support programs were used and which ones were considered most effective. Programs that were discussed include German funds managed by the German ministries for the economy and for research, the federal government's Energy Research Programs that have been in place since 1974 and the EU's Horizon 2020. Global firms also make use of available funds beyond Europe.

Many interviewees complained about the administrative burden of public research programs and the slow progress and high need for coordination in large research consortia. Another point of critique was that public funds are usually directed at basic research or early technological development and fail to make the link to a market launch. In the same vein they are also not market- and customer-oriented. Firms that view innovation very close to the market as there priority have claimed to make less use of public funds in the future.

- "You need to know how to administer [public research projects]. I created a department for this [...], that's what large firms do." (interview 26-1, incumbent div. chemicals firm)
- "We have been discussing to stay away from [research projects] with a consortium: endless discussions [...], meetings, [...] not actionable at all." (interview 9-1, incumbent foc. TSO)
- "Topics for which funds are available are not close enough to what our customers want: too lengthy, too slow and with an awkward partnership structure. […] It does not do any harm and provides for some level of activity, especially in basic research, but it is not useful for execution and application." (interview 6-1, incumbent foc. national electricity supplier)

If the objective is socio-technical change in an industry or even economy, technology-push instruments have the large downside that they do not create markets. They help create a technology, possibly even a product, but without the prospect of a market for that product the development will stop after the expiration of funds. As a consequence public R&D funds may be distortive in a sense that they encourage R&D in areas that are by the firms themselves not viewed as sustainable, because the market potential is not there. In the case of renewable energy for example, albeit the technological base was developed in the 1980s and 1990s, funded by public research grants, it only took off after deployment policies in the 2000s created a market for them. Previous development efforts were often discontinued when funding ran out. Nevertheless, research subsidies can influence the direction and rate of R&D as they lower the barrier of additional corporate R&D investment.

- "Public research funding on the supply side is nice to have, but it is prone to opportunism. Demand is what counts. […] Research subsidies can be effective […] when they lower [the risks of R&D investments] […] and nudge firms into a particular direction. But research subsidies […] cannot create markets" (interview 10-1, incumbent div. electrical/mechanical engineering firm)

These findings resonate with existing empirical research on the innovation effect of technology-push policy instruments. There is little doubt that direct investments into R&D have a positive effect on innovation activities (Johnstone et al., 2010; Peters et al., 2012; Rogge & Hoffmann, 2010; Rogge, Schneider, et al., 2011; T. S. Schmidt et al., 2012; Walz et al., 2011; Wangler, 2010). However, empirical research has also shown that they may be insufficient by themselves and especially the existence of a market is a critical complementary factor for a positive effect on innovation activities (T. S. Schmidt et al., 2012; Reichardt & Rogge, 2014).

6.3.2.2 Demand-pull instruments

The case studies show that demand-pull instruments were critical in fostering innovation activities in the context of Energiewende. Demand-pull instruments seek to induce innovation by promoting the deployment of a certain technology with command-and-control, market-based mechanisms or information. In terms of corporate innovation activities they thus affect the adoption of a technology directly, but only have an indirect, or dynamic, impact on technological exploration, development and implementation. In the course of the German energy transition especially the feed-in tariff installed by the Renewable Energy Sources Act (EEG) was instrumental as it created a market for RES-E technology and made the business case for investments in the development and improvement of such technology. Furthermore, the design features of the EEG led to a re-structuring of the energy industry by enabling small-scale electricity producers and inducing a decentralization of electricity generation. These changes to the energy system then set off another round of innovation activities regarding more systemic aspects such as smart grid, energy management and energy storage. Besides the EEG, a couple of other demand-pull instruments such as energy-efficiency regulation, and RES heating and combined heat and power incentive schemes also played a role. However, the case studies also expose difficulties. First, boosting demand in one national market may not be sufficient to incentivize large multinational firms to invest in risky technological exploration, especially if there is also doubt regarding the sustainability of such demand. Second, market growth from demand-pull instruments can become excessive and lead to opportunistic behavior especially if, again, firms do not have a long-term perspective on the market.

6.3.2.2.1 *The Renewable Energy Sources Act (EEG)*

There is a lot of evidence to suggest that the EEG was tremendously successful in terms of incentivizing the adoption of renewable energy technology. As was elaborated previously (cf. section 6.2.2.1), the EEG's attractive rate of return on electricity from renewable energy sources (RES-E) caused the mass installation of RES-E technology in Germany throughout the 2000s, as residential, commercial and industrial actors invested in solar panels, wind farms and biomass plants. Also electricity suppliers contributed to this diffusion by investing in a shift of their generation portfolio towards renewables.

Also in terms of exploration, development and implementation, the case studies find a positive effect of the EEG (cf. section 6.2.1). The growth of the RES-E markets in Germany increased potential returns and hence spurred innovation in that way. Energy technology incumbents and start-ups invested in technological improvement and the exploration of technological options in order to become more competitive.

- "It is demand that is decisive. If there is one thing that has promoted innovation towards Energiewende in Germany in the past 20 or 30 years it is the priority given towards renewable energy in the grid coupled with feed-in-tariffs. This created a market without which we would not have proper wind turbines and PV panels today. […] It turned out to be an unbelievable success. Albeit one must say, this was predictable. If it is that attractive financially, many players enter the market." (interview 10-1, incumbent div. electrical/mechanical engineering firm)
- "Private investments [in innovation] flow naturally if the market is attractive. [...] Batteries do not get cheaper in the lab [...], but through learning and scale effects." (ibid.)

And it was not only RES technology that got an innovation incentive because of the EEG. Innovation in several other technology areas was also triggered by the EEG, or, more precisely, the systemic developments that the EEG initiated. The specific design features of the EEG were remarkable in the sense that they fostered systemic change and challenged the prevailing balance of power in the energy system. Although not explicitly mentioned as a target, the EEG aimed at a decentralization of the German energy system. The fixed tariffs over an extended period of time and accessible to everybody provided attractive investment opportunities for small-scale investors, but much less to large incumbent firms who were historically used to higher rates of return. In terms of systemic regulation (cf. section 6.3.2.3.2) the EEG also ensured that all of the RES electricity produced could be fed into the grid by giving it precedence over conventionally-generated energy. As such it prevented the electricity suppliers (and later also the carved-out TSOs) from using their strategic position as owners and operators of the electricity grid to block renewable energy.

- "The change happened at such a pace that electricity suppliers did not have the time to alert to problems […] and blocked the development. They just had to integrate a lot of PV very quickly, they solved this by doing it, and it worked." (interview 13-1, start-up foc. solar tech. firm)
- "A significant characteristic of the energy transition is that it started decentral and brought thousands of new actors into the energy market. […] This is how creativity and innovation were promoted." (interview 27-1, start-up foc. solar tech. firm)

The systemic change that unfolded throughout the 2000s was marked by rising electricity generation from renewables, corresponding fluctuations in electricity load, decentral and small-scale generation, the emergence of "prosumption", the resulting strains on the grid, new players on the energy market, and declining wholesale prices due to the merit order effect (cf. section 6.2.3.5). These developments triggered innovation activities related to smart grid, energy management and energy storage (cf. sections 6.2.1.4 and 6.2.1.5) as well as business model innovation on parts of the large incumbent electricity suppliers (cf. section 6.2.3.5) in the late 2000s and 2010s. So the EEG had spillover effects on innovation activities in areas beyond its immediate target RES-E generation technology.

- "The first EEG [in 2000] this is since when we have been monitoring the system and doing smaller innovation and research activities." (interview 1-1, incumbent div. software/IT firm)
- "For us it's not the energy transition as such, but what its effects are. And the effects are that our world is becoming decentral. That is why the energy system changes. […] Our strategic direction is to develop business models for this decentral world." (interview 3-2, incumbent foc. national electricity supplier)

- "The decentralization […] and the increase in the number of small market participants […] have been underestimated. […] We are still looking for a way to enter this market." (interview 2-2, incumbent div. electrical/mechanical engineering firm)
- "Matching fluctuating generation with consumption – that's the topic that we work on." (interview 17-1, start-up foc. national electricity supplier)
- "The fluctuating renewables have made energy an interesting topic for new business opportunities." (interview 24-1, incumbent div. chemicals firm)
- "Decentral is the growth story for the coming decades." (interview 4-1, incumbent foc. municipal electricity supplier)

6.3.2.2.2 *Other demand-pull instruments*

Although it exceeds the others in its impact by far, the EEG is not the only demand-pull policy in the German Energiewende policy mix that has come up in the case studies. Other policies discussed in the course of the case studies include energy efficiency standards and incentive schemes for the deployment of renewables in heating.

A variety of energy efficiency standards have driven the exploration, development and implementation of energy-efficient technology and energy efficiency services (cf. section 6.2.1.3) as well as the adoption of energy-efficient technology (cf. section 6.2.2.2). Although no specific policies were discussed in detail during the case studies, there is a couple of regulations that define the energy efficiency standards in Germany. The Energy Savings Decree (*Energieeinsparverordnung,* EnEV) which was first installed in 2002 and revised several times, sets standards, limits and reporting guidelines for the energy use of new and renovated commercial and residential buildings. The Law and Regulation on Energy Consumption Labelling (*Energieverbrauchskennzeichnungsgesetz*, EnVKG, and *Energieverbrauchskennzeichnungsverordnung,* EnVKV) set out how to label the energy use of products. These standards, however, do not originate from German politics, but are European Union directives transposed into German law. Although transposition is not straightforward and to a significant degree influenced by national policy-making (Falkner, Hartlapp, & Treib, 2007; Steunenberg, 2007), the objectives and basic principles for these standards have hence been set outside of the realm of German politics. They are still part of the German Energiewende policy mix, but also constitute non-German environmental policy, which will be discussed later in this chapter (cf. section 6.4.1.2).

Another German demand-pull regulation that affected innovation in energy-efficiency is the requirement to have a certified energy management system if energy-intensive firms want to qualify for an exemption of the RES-E financing mechanism (*EEG Umlage*). This regulation was mentioned by case study participants as having had an influence on the development and implementation of energy-efficiency services (cf. section 6.2.1.3.2),

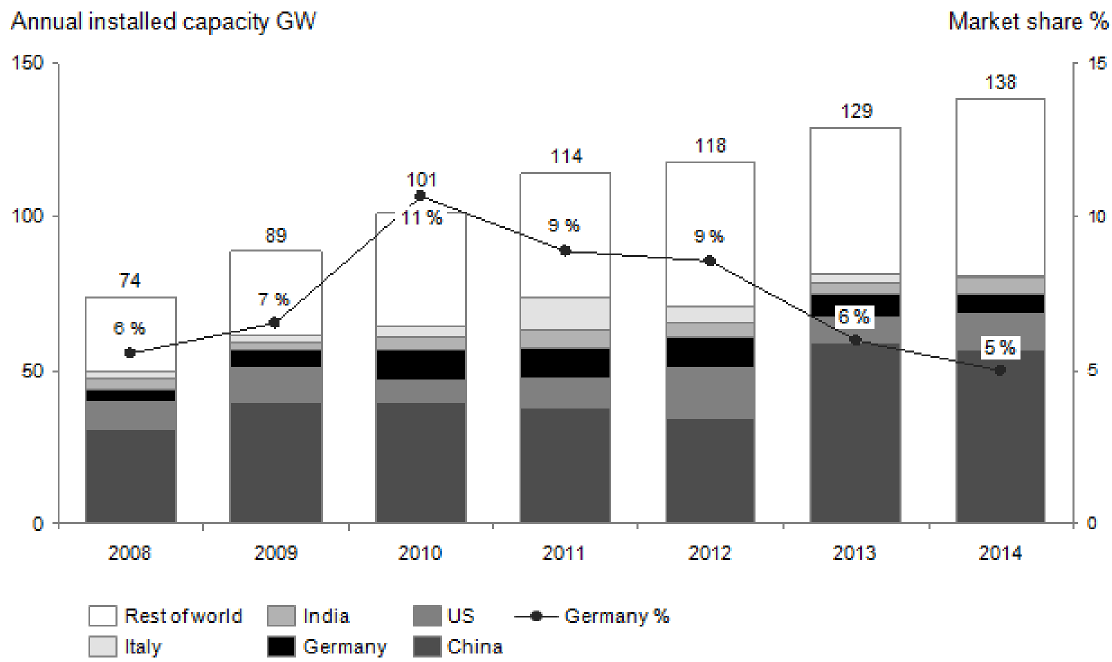
In addition, other demand-pull instruments such as the 2009 Renewable Energy Heating Act (*Erneuerbare Energien Wärme Gesetz*, EEWärmeG), which mandates a certain share of renewables for heating and cooling in new buildings, the 2002 Combined Heat and Power Law (*Kraft-Wärme-Kopplungs-Gesetz*, KWKG), which sets a feed-in-tariff for electricity generated in CHP plants, as well as unspecified loan programs by the public bank *Kreditanstalt für Wiederaufbau* (KfW), which grant interest-free or interest-reduced loans for installations related to RES-E or energy efficiency, came up during the case studies. Several interviewees have noted the allure of CHP as a technology in the context of Energiewende. Especially municipal and start-up electricity supplier have constructed CHP plants since the mid 2000s because of an attractive financial return for the power produced and the possibility to use CHP to balance fluctuating renewables. Municipal suppliers also frequently have synergy potential due to the increased efficiency of producing power and heat together. However, the frequent and considerable changes the KWKG make conditions for investment rather insecure. While these instruments appear to have supported demand for the respective technologies their impact does not seem as significant as that of the EEG on RES-E technology.

6.3.2.2.3 *Limitations and downsides of demand-pull*

While demand-pull instruments were critical drivers of innovation activities in the context of Energiewende, a couple of qualifications need to be made.

First, national demand-pull policies may only partially be relevant to the activities of global firms. Demand-pull policies do not cause technological exploration, development and implementation directly, such as technology-push instruments. Instead, they fuel market growth in a certain product or segment and this consequently triggers these activities as firms compete for a share of that market. The effect of demand-pull policies on corporate innovation activities varies greatly across the firms of the energy technology value chain depending on their respective market reaches. The case study participants have repeatedly emphasized that they define their relevant market with respect to the geographies where they engage in business activities. This means if firms are globally active, demand-pull instruments that are installed by a national government will only affect that particular fraction of a firm's demand that is in the respective country. The larger the share of a firm's market affected by the politically-induced creation of demand, the larger the impact on exploration, development and implementation. This was especially the case for the energy technology and materials firms surveyed. All of them realized the majority of their revenue outside Germany. Electricity suppliers and TSOs in contrast had Germany as their core market even if they had some other activities in other countries. This is relevant for assessing the effectiveness of the EEG as it only applied to Germany. The energy technology and materials firms surveyed claimed that while the EEG in general had the potential to incentivize innovation in RES-E technology by increasing the demand for it in Germany, their own decisions to invest depended on the development of demand across all relevant markets. Germany alone was too small to trigger significant investments in R&D. The increasing innovation activities in renewables after 2000 were hence due to global demand as not only Germany, but other countries as well, implemented RES support schemes. Nevertheless, Germany had a considerable market share of 5-10 % across all RES-E technologies (cf. Figure 22), hence the EEG was important, but it would most likely not have been if no other country had installed comparable incentive schemes. As such the EEG has supported technological development through contributing towards the expectations of a global market for such technology.

Figure 22: Annually installed RES-E capacity by country and German market share 2008 - 2014



Source: Own graphic with data from IRENA (2015)

Second, another downside of demand-pull instruments, at least where they constitute strong incentive mechanisms like the EEG, is that market growth that is too strong can lead to opportunistic behavior where firms seek to reap maximum short term benefits without having a long term perspective on the market (cf. section 6.2.1.1). Either firms enter and exit quickly, or they are led to damage their long term competitiveness by neglecting exploration, development and implementation relative to revenue, investing in production capacity instead. This might have been the case in solar PV. When the German solar PV market made up around half of the world market in the mid 2000s (cf. Figure 17) the boom associated with the EEG provided such an incentive. However, as stated earlier, not all firms subdued to such opportunism. In fact all of the firms interviewed with activities in the solar industry stressed their continuous commitment to innovation in solar PV, however, they did not rule out that in the wider industry such behavior might have taken place.

Third, following both qualifications just made, case study participants were wary of the installation of strong "EEG-type" incentive mechanisms for other technologies. Looking at areas that will have to develop in order to successfully complete the energy transition, energy storage, smart grid, or energy management technology could also benefit from a boost in demand. Interviewees noted repeatedly that the main reason why development in these technologies is comparatively slow is because there is little market demand for them currently. However, despite this the firms surveyed did not support incentives for energy storage or distributed energy in the same way that the EEG incentivized renewables, claiming that it would distort the market: a strong incentive such as, e.g., paying a feed-in-tariff for electricity from storage would enforce an artificial regulatory selection of technology, rather than a natural market-based one. Furthermore, it would entail the risk of overheating the market just as happened in solar PV.

- "The problem [with solar PV feed-in-tariffs] was that the industry had a learning curve too steep for politics to follow. […] Degression always came too late, because it was a political process." (interview 19-1, start-up foc. solar tech. firm)
- "If my business case depends on returns that are not generated by market mechanisms I run a portfolio risk. […] I've stressed this in all political discussions regarding energy storage. Short term we would of course like to

have subsidies, but it does not help us long term." (interview 21-1, incumbent div. chemicals firm)

These findings regarding the impact of demand-pull instruments in the context of Energiewende are largely in line with existing research in environmental economics. Demand-pull instruments are generally attributed a critical role in environmental innovation (Jaffe et al., 2003; Jaffe & Stavins, 1995; Nemet, 2009; Peters et al., 2012). A closer discussion of the significance of the EEG, also in light of the controversy identified at the beginning of this thesis (cf. section 4.3), as well as the potential negative effects of strong policy-induced market growth will follow in the next chapter.

6.3.2.3 Systemic regulation

The case studies show that systemic regulation has also affected innovation activities. In the context of innovation policy, systemic policies are typically understood as policies that affect the performance of an innovation system. Such policies are mainly directed at communication, interaction and knowledge sharing between players in innovation systems (Smits & Kuhlmann, 2004; Wieczorek & Hekkert, 2012). Clearly these are important, but were in no particular focus and did not emerge as relevant topics from case studies conducted for this thesis. The systemic policies that were discussed during the interviews are directed at the functioning of the energy system in Germany at large, not specifically the innovation system.

The systemic instruments identified from the case studies are laws and regulations governing access to and pay-offs from elements of the energy system, be it the physical generation, transmission and distribution of electricity, or the virtual trading of it. Such laws and regulations form the basis of the governance of network industries, such as the electricity sector, and the operation of regulated traded markets, such as electricity exchanges. They have an indirect effect on innovation activities through setting the basic rules and framework conditions in which firms have to operate. As such they do not lower the barriers of R&D investments (such as technology-push instruments) or provide a strong incentive to act (such as demand-pull instruments), but more subtly enable or disable certain conduct e.g., by providing the access and return required to participate in a market that will yield returns for a novelty in the first place. Systemic regulation can constitute a gateway, but also a major barrier to innovation e.g., by restricting market access limiting the ways to make money in a market. Four incidences of political intervention, some enabling, some restricting, turn out to be of particular importance; the liberalization of the electricity sector in the 1990s, the systemic elements of the Renewable Resources Act (EEG), rules and regulations for electricity market participation, and electricity market design.

6.3.2.3.1 *Liberalization of the electricity sector*

The amendments to the Energy Industry Act (*Energiewirtschaftsgesetz*, EnWG) in 1998 implemented an EU directive to liberalize the electricity markets. This permitted the exploration, development and implementation of new business models in the electricity industry and consequently the emergence of new actors such as electricity suppliers and traders with no physical generation assets (cf. section 6.2.3.5.1). As these new actors are very active innovators now especially in critical areas such as smart grid, energy management, energy storage and respective business models (cf. sections 6.2.1.4, 6.2.1.5, and 6.2.3.5) , the liberalization was an important early enabler of some of the innovation activity in the electricity supply sector that is envisaged today. In addition to this, incumbent electricity suppliers have mentioned liberalization as an important driver for their business as a whole, however, not clearly so for innovation activities. One electricity supplier affirmed that they diversified their innovation activities after liberalization presented them with more market opportunities. Another one contemplated cost reductions after liberalization that cut into the funding for non-targeted, exploratory technological projects. It is hence clear that liberalization had an important impact on all activities in the sector, however not a unidirectional and unambiguous one.

- "We divested [PV] through liberalization, financial results pressure and lack of effect." (interview 3-1, incumbent foc. national electricity supplier)

These findings are roughly in line with, but further illustrate empirical findings in environmental economics on the effect of liberalization on innovation in the electricity supply sector. Liberalization seems to affect priorities and intensity of innovation activities and outputs in the electricity sector, however, is no kick-start for innovation per se. Jamasb and Pollitt (2008, 2011) find a decline of R&D expenditures following the liberalization of electricity supply in the United Kingdom, but at the same time a rise in R&D productivity and outputs, such as patents. Tõnurist, den Besten, Vandeven, Yu and Paplaiyte (2015) investigate subsequent rounds of electricity market liberalization in Belgium and the Netherlands and discover that innovation has tended to become more customer-oriented and dynamic because of market competition, but R&D spent overall has declined and the diffusion of new technologies (in their cases RES-E generation technology) does not seem to be positively affected. For the case of the German Energiewende, the liberalization of the 1990s has introduced competition in the electricity sector which in turn has shaped all activities of the actors involved subsequently including innovation activities. It has previously been shown that renewable energy policies are more effective in countries with liberalized energy markets (Nesta, Vona, & Nicolli, 2014) This competition probably facilitated innovation towards a sustainable transition of the energy system, but did not trigger or exclusively determine it.

6.3.2.3.2 *Systemic elements of the EEG*

In addition to the EnWG and liberalization, another systemic instrument was critical to innovation activities through its impact on market access. The EEG, mainly known for its feed-in tariff, a demand-pull instrument, also has elements of systemic regulation. The priority and guaranteed grid access for electricity from renewable energy sources (RES-E) was instrumental as an enabler of systemic change. Since it is difficult to separate the effect of this systemic aspect of the EEG from the feed-in tariff, the combined effect of the two has already been discussed in the previous section (cf. section 6.3.2.2). To briefly summarize here, the priority and guarantee given to electricity from RES ensured market access and consequently the pay-off from an investment in RES electricity generation technology. Without this element incumbent market participants in strategic positions (i.e. owners and operators of distribution and transmission grids) might have had the opportunity to rig market access and hence reduce the attractiveness of the feed-in tariff. As such the systemic element of the EEG contributed to its success in terms of RES deployment. Furthermore, it also supported the change of the German energy system as a whole by allowing non-incumbent producers of electricity to access the market. In a series of dynamic effects this lead to the rise in renewables and decentralization of electricity generation that underpins the change of the German energy system.

6.3.2.3.3 *Rules and regulations for energy system governance*

However, systemic regulation in the context of Energiewende has not only had an enabling role. Some of the rules and processes for the governance of the energy system in Germany that were set by the EnWG have proved to be rigid and inflexible when it comes to innovations. This has impeded the successful implementation of some inventions, especially those that seek to introduce new nodes, new activities or new ways of compensation in the system.

Actor conduct in the electricity system is governed primarily by the German network industries regulator *Bundesnetzagentur* (BNetzA). The BNetzA sets rules and regulations such as compensation mechanisms and permissible returns for grid operators and standards and process of grid planning and accounting (*Bilanzkreismanagement).* These rules determine how the electricity system is operated and are hence manifestations of a particular way of understanding its functioning and priorities.

An example where these rules and regulations have constituted an obstacle for change is the struggle of demand side energy management providers to integrate their service offering into the energy system. At the outset of their efforts around 2010 the rules and regulations to maintain stability of the transmission grid network were only defined with respect to electricity supply, not electricity consumption. That means while suppliers could be rewarded for increasing or decreasing electricity supply to balance electricity load in the grid as needed, rewards for increasing or decreasing electricity demand were not defined. Raising awareness and implementing the required regulatory changes took years i.e. impeding, or at least delaying, the implementation of demand management (cf. section 6.2.1.4). The complex regulation has hence constituted a barrier to innovation in at least this area.

- "Liberalization has not made it easier to implement new solutions. Because we have a separation of the electricity grid and market that is cemented in the management system for grid planning and accounting[1] it is really hard to implement changes. […] You can have an amazing innovative idea, but not be able to introduce it to the market if you have not written the law and regulation for how to implement it in advance." (interview 16-1, start-up foc. software/IT firm)
- "[I wish politics] left space for liberal markets and new business models wherever it is possible." (interview 18-1, start-up foc. electricity supplier)

Another example is the provision of innovation and modernization incentives to transmission and distribution grid operators. As their returns are fixed by the network regulator, excess cash to invest in innovation activities for invention, implementation or diffusion needs to be acquired through special regulatory mechanisms. The case studies

[1] The German term *Bilanzkreismanagementsystem* for was used in the German interview

provided some evidence that especially in the case of DSOs the current mechanisms may not be sufficient to ensure the required extension of distribution grids and in particular their update to become smart grids (cf. 6.2.2.3).

Both examples may hint to a possible failure on part of policy makers to anticipate the systemic implications of their decisions and consider how established systemic regulation and the objectives and effects of other policies, such as vision and strategy or demand-pull instruments and how it might have to be adjusted. This was frequently contemplated by case study participants. Systemic regulation requires policy makers to have very detailed expert knowledge of the areas supposed to be regulated. The energy system is a particular challenge with a high degree of complexity as it combines a physical supply, transmission and distribution system with virtually traded contracts and markets. Throughout the case studies a failure to foresee and adequately address the systemic consequences and requirements of other policies was mentioned in a couple of areas, e.g., regarding the fast growth of renewable energy generation and the delay in developing corresponding plans for an extension of the physical grid in order to be able to connect renewable capacity and transport electricity to places of consumption far away, a possible change of electricity market design to provide for adequate reserve capacity, and the aforementioned flexibility of the grid planning and accounting system to integrate novelties and investment incentives to grid operators.

- "With the increase of renewables it became foreseeable […] that the energy system needs to be overhauled; not only technologically, but also in terms of regulation." (interview 16-1, start-up foc. software/IT firm)
- "There are very few experts that understand the clashes that can take place on the most granular levels of detail. […] [Politicians typically don't.]" (interview 16-1, start-up foc. software/IT firm)
- "In many areas there is so much contradiction that there is no clear market signal." (interview 6-1, incumbent foc. electricity supplier)
- "When you define market rules you automatically limit the range of possible technological solutions that emerge." (interview 13-1, start-up foc. solar tech. firm)

These findings are largely in line with what would be expected from the theoretical and empirical literature on the impact of such systemic laws and regulations on innovation activity. While there is little empirical research in this particular area, applying theoretical knowledge from evolutionary economics and sustainability transitions (cf. chapter 2) one would expect institutional change such as the adaptation rules and regulations to be slow and path dependent and especially institutions at a very low level of granularity to be among the last to adapt. This tension will be further discussed later in this thesis (section 7.2.1).

6.3.2.3.4 *Electricity market design*

Lastly, the current debate about electricity market design i.e. the definition of the individual tradable market segments in the electricity wholesale market and the way in which market participants are compensated also bears on innovation activities. On a very simplified level, there are two basic principles for the organization of wholesale electricity markets: First, in an *energy only market* only the provision of electric energy is explicitly compensated for. This means the market price is determined based on the marginal supply of and demand for energy. This is the market principle in the German electricity markets today[1]. In contrast to this, in a *capacity market*, the provision of electric capacity is compensated in addition to electric energy. I.e. even power plants that are not running or not running at full capacity can earn a return just for being able to provide that capacity to the market if required. At the time of the empirical research (2015) the German government was contemplating a reform to the electricity market design with the potential introduction of a capacity market.

The link between electricity market design and innovation is a very indirect one, yet nevertheless important. New business models and products will be oriented on the pay-offs they can generate in a given market design and little effort will be put into developing and implementing these as long as the market design question is not solved. Furthermore, for market participants with large electricity generation capacity, i.e. incumbent electricity suppliers, the electricity market design has a significant effect on the returns of their assets hence their financial situation overall. A capacity market has the potential to improve their strained finances and make available more resources, for example, to put into innovation activities.

There was a general consensus among case study participants that a capacity market or capacity mechanisms are important to adequately reward the provision of reserve capacity to balance fluctuating renewable energies. Clearly this is not a surprise for incumbent electricity suppliers, however, also start-up firms tended to express support for capacity

[1] This explanation remains extremely simplified. A detailed discussion of the German electricity market design and alternatives to it can be found in the BMWi (2014b) Green Paper for electricity market design.

markets. Furthermore, participants agreed that the electricity market should be designed in a way that flexibility is rewarded, without elaborating this point in more detail. None of the case study participants explicitly mentioned an impediment of innovation activities given any particular outcome of the electricity market design debate. However, anticipated returns from electricity trading will certainly influence the selection of viable products, technology options and systemic elements and hence determine the future set-up of the energy system. Just exactly how this will look like is difficult to anticipate at the moment.

- "The extreme growth in renewable energy is not compatible with the current electricity market design." (interview 17-1, start-up foc. electricity supplier)
- "[In the discussion about electricity market design] innovation is not a big topic currently. However, […] [innovation] is also about the competition between different technologies, and markets are the best way to discover the technologies that will be successful in the future." (interview 6-2, incumbent foc. electricity supplier)

Also, although energy-only markets versus capacity markets is the major debate right now, it might in fact only have limited impact on the transition of the energy system. Empirical research indicates that while capacity mechanisms naturally provide an incentive for increased investments into generation capacity, esp. of the conventional type, they do not per se encourage measures for a more efficient energy system such as demand response management or ancillary services to stabilize the electricity grid (Roques, Newbery, & Nuttall, 2005; Roques, 2008). The authors conclude that electricity market reforms should target these areas first before worrying about capacity mechanisms.

6.3.3 Process

The case studies show that as the last element in the Germen Energiewende policy mix also the policy process had some impact on innovation activities, albeit it seems to be less relevant than the previously discussed aspects. Policy process refers to the series of steps through which policies come into existence, are implemented and changed. While the policy process of Energiewende naturally started with the environmental movement in civil society and politics following the 1970s oil crisis (cf. section 3.3.1), the focus of the case studies turned out to be the more recent policy process and the evolution of energy policy and Energiewende since the installation of the EEG and the nuclear exit of 2000. Two aspects relevant to innovation activities were discussed in particular with regard to policy processes;

first, perceived uncertainty of the policy process, and second, corporate participation in its outcome.

6.3.3.1 Uncertainty and volatility regarding the outcomes of the policy process

Many case study participants have perceived the past political process regarding Energiewende as messy, incoherent, and to a certain degree even arbitrary. This perception stems especially from the back-and-forth regarding nuclear exit. The nuclear phase-out decision of 2000 was recurrently questioned and debated in the years following its implementation, eventually softened with longer phase-out periods in the 2010 Energy Concept and finally accelerated with the definite decision to end all electricity production from nuclear sources by 2022. In addition, some smaller political processes and turnarounds in the political endorsement of certain technologies or applications e.g., solar PV, combined heat and power, or the exemption from the EEG financing mechanism for electricity suppliers (*Grünstromprivileg*) have also fuelled wariness of the reliability of political opinions and policy mixes, esp. where they pertain to financial support for such policies.

However, it has not become entirely clear from the case studies to what extent and how this critique of the political process has affected innovation activities. In general, the allegation that underlies the critique of a messy policy process is that market opportunities that rely on political sentiment or concrete financial support measures cannot be fairly evaluated and may rise or fall along with the changing course of politics. Markets may be unsustainable because they are not based on fundamental demand and the political will that may uphold them on one day may fade away on the next day. If firms do not expect a market potential longer term they are unlikely to make substantial investments into the exploration, development and implementation of novelties for these markets. Instead they may rush in and out to reap the benefits but not invest for the longer term. The potential risk that strong, but unsustainable political incentives can lead to short term opportunistic behavior on parts of market participants has already been elaborated in relation to the boom and bust in solar PV (cf. section 6.2.1.1 and 6.3.2.2.3).

This uncertainty also exists regarding currently ongoing policy processes and the future set-up of the energy system. The greatest worries of case study participants are the continuation of the EEG and the direct marketing of renewables, as well as the systemic regulations and incentive mechanisms that will guide the further transition of the grid infrastructure towards smart grids and demand and supply side energy management.

Especially for the latter one where technological exploration is still required firms note a hesitation to invest in exploration, development and implementation as well as in diffusion given the uncertainty of what solutions are likely to yield the best returns in the future.

- "Systemic solutions, smart grids and smart market are important now. […] The uncertainty of where [regulation] is going is a challenge." (interview 13-1, start-up foc. solar technology firm)

The environmental economics literature has long realized that regulatory uncertainty plays a role in innovation activities, albeit typically rather in connection with policy instruments rather than the policy process (Engau & Hoffmann, 2011; Rogge, Schleich, et al., 2011). It has, however, also been shown that the effect is not necessarily negative. Instead, firms have a variety of options to address uncertainty that ranges from not engaging in innovation at all to engaging in it even stronger (Engau & Hoffmann, 2011). The inconclusive findings here with regards to an effect of uncertainty on innovation activities are hence in line with the literature.

6.3.3.2 Corporate participation in policy making

Another topic discussed was the participation of firms in policy making through, e.g., formal consultations, green and white papers, expert statements and summits, or lobbying, and the link of these to innovation activities. Findings from the case studies are divergent indicating on the one hand that early involvement in the policy process provided an inspiration for firms to reciprocate the political efforts with Energiewende related innovation activities, on the other hand, political participation and especially lobbying was also used to cement the status quo and hence rather as a substitute to innovation activities.

There was some evidence that early involvement in the political process motivated actors to start innovation activities where they would not have done so otherwise. One case study participant, an incumbent energy technology firm, described the expert opinion on energy efficiency that his firm was asked to deliver at a federal government energy summit in the mid 2000s as an important accelerator for their energy efficient modernization of buildings and production facilities as well as the exploration of further technological opportunities for energy efficiency and renewable energy. Overall most firms valued the participatory policy-making style employed of the German federal government and the input as exemplified by e.g., the 2015/2016 green and white paper process for the electricity market design reform.

However, the case studies also provide evidence for the allegation frequently voiced by renewable energy advocacy groups that lobbying was used esp. by large incumbent electricity suppliers to try to contain the energy transition in an effort to put off firm-internal innovation activities and change processes (Bontrup & Marquardt, 2015). Large electricity incumbents, and to a smaller extent also the affected energy technology firms, sought to influence policy-making throughout the 2000s with the ambition to revert the nuclear exit decision, diminish the influence of renewables and in general shape the energy transition in their favor. Focusing their efforts on preserving the status quo instead of preparing for change, they delayed certain activities to explore new business areas or not considered them necessary given there was still a chance to return to the cash cows of written-off nuclear and fossil fuel power plants.

- "It's partially a reaction typical for this [electricity] industry; if we are not 100% convinced by a certain technology, we will fight it instead of searching for its potential." (interview 6-2, incumbent national electricity supplier)

It was only after the 2011 Fukushima nuclear incident that the energy transition in terms of renewables without nuclear was understood as being irreversible. As explained before (cf. section 6.2.3.5), it was this development that triggered the big push towards esp. business model innovation activities envisaged in the electricity sector.

6.3.4 Synopsis: impact of the Energiewende policy mix

This section has discussed the impact of the individual components of the Energiewende policy mix on innovation activities of firms of the energy technology value chain. The findings provide strong evidence that all elements of the policy mix considered had some effect on innovation activities. However, rather than confirming an effect or even indicating an effect size, the objective of the case studies and the contribution of the theoretical and methodic approaches chosen, was to explore the nature of this effect. Indeed, the case studies show that while all elements have tended to have a positive effect on innovation activities, there are also ambiguous effects that need to be considered for a holistic assessment. An overview of the most important findings is presented in Table 14 below.

The vision and strategy that has been formulated over the course of the German Energiewende has constituted an important point of reference for the future development of the German energy system that firms have taken into account when determining the strategy, direction and intensity of innovation activities for the longer term. The strategic decisions, such as the nuclear exits in 2000 and 2011, and long-term targets for GHG emissions, renewable energy and energy efficiency have provided a cue towards how the associated markets will develop over the long term. This anticipated development of markets is an input for firms' strategy development and planning regarding innovation. It influences expectations of the future and activities targeted at the long term. It is, however, less powerful to influence immediate and short-term corporate activities. In terms of innovation activities, they tend to be more important for exploration, development and implementation, than for adoption or organizational change, possibly with the exemption of the business model changes that were initiated following the 2011 nuclear exit. However, to be taken as a basis for future decisions, it is important that the political vision and strategy is credible. The limited effect on innovation activities of the first nuclear exit was due to the fact that the affected firms did not believe it would actually happen in the way set out. In the short term, other components of the Energiewende policy mix are more important. Although in the short term other policies may have a stronger impact, they are vision and strategy is essential to guide corporate behavior for the longer term.

Technology-push policies have had an effect especially on exploration, development and implementation as the public financial contributions to R&D have lowered the barrier and increased the risk sharing of investments into these activities across a wide range of technologies and applications. They also contribute to building multi-actor networks in R&D. Public funds are extensively used despite the administrative burden that the distribution of public money entails. However, the downside of technology-push is that the technological development achieved is not sustainable if no market demand for the in question technology exists. Ultimately firms will base their decision to pursue innovation activities on the prospect of earning a return from these activities and discontinue activities where sufficient market demand does not exist. Hence technology-push can be very effective for technological development, especially if the technology is still in its infancy, but is ultimately not sufficient without a market to sustain it.

Demand-pull policies with economic incentives, command-and-control regulation and informational instruments have been decisive for all types of innovation activities studied. Primarily the Renewable Energy Sources Act (EEG) has set an incentive for the adoption of RES-E technology and hence created a market for such technology that has in turn provided an indirect incentive for further exploration, development and implementation of RES-E and complementary technologies. Energy efficiency standards have done the same for more energy-efficient technology and energy efficiency consulting services. However, the case studies have also revealed a couple of limitations and downsides of demand-pull policies. First, the incentive set by demand-pull policies may not be sufficient for large investments in exploration, development and implementation if the market affected by a demand-pull policy constitutes too small a share of the market relevant for the investing firm in question. Second, strong market growth may create opportunistic behavior on parts of firms. Third, firms may be wary of the continuation of such demand-pull policies, especially where they constitute a financial incentive, and put off investment in the expectation that the market created is not sustainable.

Systemic regulation has constituted an enabler as well as an obstacle to innovation activities. While systemic regulation such as rules governing market access, conduct and pay-offs in network industries, is usually in the background and not often discussed with respect to their innovation impact, the case studies show that it has been important in the context of Energiewende. As systemic regulation defines the conditions under which players in regulated industries operate it sets the framework for the successful implementation of and return from innovations.

The policy process has also influenced innovation activities. Uncertainty regarding its outcomes was noticed by firms. Corporate participation in policy-making can increase the commitment and willingness to be innovative regarding a certain topic, however, the case studies have also hinted that intensive lobbying for preserving a status quo can to a certain extent be used to put off activities related to corporate change.

Table 14: Key findings regarding an innovation effect of Energiewende policy mix components

Policy mix category	Policy mix component	Key findings regarding an innovation effect
Vision and Strategy	First nuclear exit	• Limited effect on innovation activities because it was not considered credible
	Long term targets • Energy Concept	• Limited effect on innovation activities in the short term • Provided important guidance regarding the future market demand for RES, energy-efficient and other climate-friendly technology
	Accelerated Energiewende	• Did for most firms not affect the strategic direction of innovation activities, but strengthened the overall change dynamics • Triggered business model innovation in electricity suppliers
Instruments	Technology-push instruments: • R&D support	• Used by almost all firms to reduce financial burden and risk of technological exploration, development and implementation • Triggered the building of R&D networks • Did not constitute a viable substitute for the existence of markets
	Demand-pull instruments: • Renewable Energy Sources Act (EEG) • Various energy	• EEG directly supported technological adoption and hence created a market for RES-E and complementary technology • EEG indirectly triggered exploration, development and implementation of in RES-E and complementary technologies

	efficiency regulation • Renewable Energy Sources Heating Act, CHP Law	• EEG design features promoted systemic change, which in turn triggered exploration, development and implementation in all areas needed for an RES-based energy system • Energy efficiency regulation promoted innovation activities in relevant products, processes and services • Other demand-pull instruments had comparatively limited impact on innovation activities • Strong policy-induced market growth involves the risk of opportunistic behavior at the expense of innovation activities • Firms tended to be cautious to invest in markets that depend on political support • Were only effective to the extent that the market influenced was attractive enough to firms
	Systemic instruments	• Had an indirect effect through setting the framework conditions in which firms operate • Constituted barriers as well as enablers for innovation activity
Process	Volatile process	• Was noticed, but did not affect innovation activities in any specific direction
	Corporate participation	• Provided motivation as well as impediment to innovation activities

6.4 Impact of context factors and firm characteristics

While the Energiewende policy mix clearly had an impact on innovation activities, as elaborated in the previous section, it was not the only factor. The case studies show that a number of context factors and firm characteristics influenced innovation activities. Influences were either independent of the Energiewende policy mix or together with it as mediating or moderating factor. Many of these confounding factors were already mentioned in the previous sections when they were relevant. This section summarizes them and discusses the nature of their interaction with the Energiewende policy mix.

6.4.1 Context factors

6.4.1.1 Market and industry dynamics

The case studies reveal that market and industry dynamics are critical drivers of innovation activities. Even stronger than this, they may indeed be the most important group of influencing factors. Especially market factors such as customer demand or the prices of inputs and outputs came up in each of the case studies and were always cited as critical influences to innovation activities. However, evidence from the case studies also suggests a strong interaction between some of the relevant market factors and the Energiewende policy mix. As such the market and industry dynamics discussed during the case studies constitute, at least partially, dynamic effects of environmental policy. Several market and industry dynamics were mentioned by case study participants as decisive for their decisions to pursue innovation activities.

First and foremost, the development of a market i.e. the strong increase in customer demand for environmentally-friendly energy without greenhouse gas emissions was a critical driver behind the exploration, development and implementation of relevant technologies. Customer demand and market potential were mentioned as a reason for innovation activities in RES technology for electricity, heating, and transport (cf. section 6.2.1.1), conventional non-emitting electricity generation technology (cf. section 6.2.1.2) and energy efficiency (cf. sections 6.2.1.3). Moreover, the demand for solutions for an energy system relying exclusively on RES, which emerged when RES gained market share and systemic relevance in the mid-to-late 2000, promoted innovation activities in such solutions incl. smart grid, supply and demand side energy management, and energy storage (cf. sections 6.2.1.4, 6.2.1.5).

Second, the expectation of higher energy prices constituted a motivation for innovation activities in energy-saving as well as alternative energy technologies throughout. The starting point to explore RES technologies was the oil crisis and corresponding price spikes in the 1970s (cf. section 6.2.1.1.1). Innovation activities in energy efficient products, processes and services were always critically motivated by the fear of higher prices of electricity and other forms of energy (cf. sections 6.2.1.3 and 6.2.2.2).

Third, lower energy prices have also triggered innovation activities. The losses incurred on conventional generation assets due to the declining wholesale electricity price in Germany since 2011 were critical in fostering the attempts for business model innovation of incumbent electricity suppliers (cf. section 6.2.3.5).

Fourth, competition from incumbent or start-up firms also increased the pressure to conduct innovation activities. Incumbent energy technology firms noticed the emergence of RES technology start-ups. At first they were, however, not perceived as competition, but rather firms operating in a different market, namely the market for small-scale electricity generation (cf. section 6.2.1.1.1). When the RES market expanded, these start-ups were first considered attractive take-over targets and then slowly evolved into competitors for the best product offering. Moreover, electricity suppliers and energy technology firms perceive competitive threats from outside their core industries. For electricity suppliers the emergence of small-scale RES-E producers empowered by the EEG was a surprising disruption, but did not have a serious effect on innovation before the systemic change was recognized. Currently electricity suppliers increasingly perceive their industry to be invaded by energy technology firms from the more upstream sections of the energy technology value chain and firms from energy-related industries that have historically been separate from electricity. Energy storage offerings from battery producers or operators of electronic vehicles fleets with the capacity to feed electricity into the electricity grid for example overstep into the traditional business area of electricity suppliers (cf. section 6.2.1.5). In addition, all firms in the energy technology value chain fear an overhaul of their sector through the activities of IT and high technology firms. Throughout the case studies caution of these new competitors has been prominent. Business model motivation in the digital realm (cf. section 6.2.3.5.3) as well as smart grid and energy management product offerings (cf. section 6.2.1.4) are specifically influenced by this competitive threat. So far, however, no significant disruption has taken place.

Many of these market and industry dynamics were in fact created or influenced by the policies of the German Energiewende policy mix, especially the EEG. First of all, the EEG was the decisive factor that increased the demand for RES-E generation technology in Germany since 2000 (Held et al., 2006; Mitchell et al., 2006; Haas et al., 2011a; Jenner, Groba, & Indvik, 2013). Because of the impact of the EEG the installed RES-E generation capacity expanded from 17 GW in 2000 to 97 GW in 2014, a growth by almost 600% over the period (cf. Figure 7). As a consequence of RES-E capacity additions, electricity from RES gained a significant share of the German energy mix. It also empowered private and small corporate firms to invest in RES-E generation capacity, hence changing the customer structure for energy technology firms and creating new competitors in the generation business for electricity suppliers. Second, the necessity to make changes to the German energy system in order to make it fit to cope with decentral and fluctuating electricity supply was a direct consequence of the increasing share of RES-E in the German electricity mix. Third, the decline in wholesale electricity prices after 2011 was also a consequence of the higher generation of electricity from RES. Fourth, one of the factors influencing the current fear of higher electricity prices in Germany is the financing mechanism for the EEG (*EEG Umlage*) which redistributes its costs to the electricity bills of residential, commercial and industrial electricity consumers, although at the moment some energy-intensive industries are exempted from it to preserve their competitiveness.

The critical role of market and industry factors has been well described in the environmental economics as well as the organization and management literature (Hippel, 2005; Hoppmann et al., 2013; Horbach, 2008; Jaffe et al., 2003; Schmookler, 1962). Also the dynamic effects of demand-pull policies do not come as a surprise. The role of the EEG in that respect will be further discussed in the next chapter (cf. section 7.1.1).

6.4.1.2 Non-German environmental policy

The case studies show that not only the German Energiewende policy mix affected innovation activities, but also politics and policies in other countries, on the European level and in the international policy arena.

In the same way that German deployment schemes for renewable energy created a demand for RES technology, similar demand-pull policies did so in other countries. Many countries installed such schemes in the late 1990s and 2000s and for energy technology and materials firms active in the global market the combined effect of these influenced their decisions regarding innovation activities (cf. sections 6.2.1.1.2 and 6.2.2.1).

Moreover, some of the German laws discussed and identified as relevant to innovation activities are mere transpositions of European Union (EU) directives into national law, although national governments typically have some discretion over the final outcome (Falkner et al., 2007; Steunenberg, 2007). This is the case for the liberalization of the electricity sectors, which has it origin in the EU effort to liberalize and extend the Single European Market (SEM) to an ever wider range of products and services (Jamasb & Pollitt, 2005b). It has been above that this liberalization provided the basis for much of the innovative activity seen in the electricity supply industry later (cf. section 6.3.2.3.1). Furthermore especially in energy efficiency many of the German laws have their roots in European legislation. Several case study participants mentioned these as being directly relevant for their decision to engage in more innovation activities for energy efficient products and services (cf. section 6.2.1.3.1). The same holds for smart meters in private households (cf. section 6.2.1.4.3). In both areas it is unlikely that innovation activities would have taken place to the extent that they have, had it not been for EU legislation.

In addition, other EU regulations as well as international politics and policies also affected innovation activities. The European Emissions Trading Scheme (EU ETS) as well as the Kyoto Protocol and other international multilateral climate protection efforts were mentioned. Especially some energy technology firms note that it was climate change regulation on an international and European level that fostered their innovation activities, however, this was mainly discussed in the context of the decarbonization of conventional electricity generation technology (cf. section 6.2.1.2.1).

6.4.1.3 Landscape developments

Also developments and events on the landscape levels have affected innovation activities.

The case studies show that the progress in information technology that has taken place over the past two decades has had a tremendous effect on innovation activities across all firms. Technological advancements taking place through the growth of computing power, the development of mobile internet, the internet connection of technical appliances, and most recently augmented reality and artificial intelligence define the playing field in all sectors. Key words exemplifying these developments such as "internet of things", "smart home" and "Industry 4.0" were very prominent in the discussions about innovation in the case studies. When it comes to the innovation activities observed, however, digitalization primarily functions as an enabler, rather than a driver of these activities. The possibilities provided by digitalization constitute the opportunity space for new solutions in the energy system. That means they do not motivate innovation activities as such, but they influence the direction of activities conducted once the need to conduct them has been realized. This is especially prominent in the developments in smart grid and energy management (cf. section 6.2.1.4). For example, the need to develop solutions for the grid to cope with the fluctuating electricity from renewable energy sources (RES-E) was driven by the increase in RES-E generation, which was in turn a result of demand-pull energy policy (cf. section 6.3.2.2). However, the attempts to address this need through smart grids and supply and demand side energy management resulted from the unfolding technological developments.

Another landscape development that was repeatedly mentioned by companies as an important consideration for their innovation activities was the trend towards environmentalism embodied in the development of pro-environmental public opinion since the 1970s. The vocal support for green technologies, renewable energy and the rejection of nuclear energy was noted and reacted upon by firms. This seems to have played a role for exploration, development and implementation activities regarding renewables (cf. section 6.2.1.1), conventional generation technology (6.2.1.2), and energy-efficiency (cf. section 6.2.1.3). It was also a factor that led electricity suppliers to adopt RES-E generation capacity and modernize power plants to reduce their CO_2 emissions (cf. sections 6.2.2.1 and 6.2.2.2).

Digitalization as well as environmentalism are commonly recognized as societal megatrends that influence all aspects of society (Rosenberg, 2001; Slaughter, 1993b; N. H. Stern, 2006; Tapscott, 1996). Other such megatrends such as changing global income structures or demographic change did not turn out to be of significance in the case studies.

Lastly, in addition to the general developments, some specific events also influenced innovation activities. Most noteworthy are the nuclear incidents at Chernobyl (1986) and Fukushima (2011) that drove the opposition to nuclear energy in Germany and hence fuelled the environmentalism elaborated above. In addition, electricity black-outs alerted firms that systemic changes in the energy system were taking place (cf. section 6.2.1.4.3).

6.4.2 Firm characteristics

6.4.2.1 Value chain position

It has become apparent throughout the presentation of innovation activities and innovation dynamics (cf. section 6.2) that firms in different value chain positions have fared differently. The distinction between electricity suppliers and energy technology firms set out in the conceptual framework (cf. section 5.2.4) and explanation of the research case (cf. section 5.3) hence proved to be a useful one.

First, as was to be expected, the nature of the innovation activities tended to differ across the two value chain positions. Being on the lower end of the value chain, in a services industry that does not develop technologies themselves, electricity suppliers and grid operators predominantly considered their innovation activities to be the adoption of new technologies and the contribution to their development and implementation by being partners in demonstration projects. The engagement in technological exploration and development activities in energy generation or grid technology is traditionally rare. However, this is slightly different for products and services involving information technology, such as applications related to energy management. Here electricity suppliers tended to engage in more development work themselves, albeit typically together with partners (cf. section 6.2.1.4). Electricity suppliers and grid operators also heavily engaged in innovation activities in terms of organizational changes, especially business model innovations (cf. section 6.2.3.5).

In contrast to that, energy technology and materials firms occupy the upper part of the value chain and have the largest share of their innovation activities in the exploration, development and implementation of new technologies and materials. Aside from the adoption of energy-efficient products for their own operations (cf. section 6.2.2.2), adoption was hardly discussed as an innovation activity. Organizational change plays a role for energy technology and materials firms just as it does for electricity suppliers, however, possibly to a smaller extent. Energy technology and materials firms created new business units and innovation teams especially for Energiewende related topics and adjusted to the structural changes in the energy system by developing product and service offerings specifically for new types of customers. However, their business model did fundamentally not change as they were overall affected to a smaller extent than electricity suppliers and grid operators, see this section below.

Second, there is a clear difference in the extent to which the individual value chain steps were affected in their innovation activities by Energiewende policies. Clearly, the effect on the downstream firms in electricity supply and grid operation has been more fundamental than the effect on the upstream firms in energy technology and materials. This is due to the differences in exposure to Germany as a country and the electricity sector as a market. Electricity suppliers and grid operators based in Germany typically realize the majority of their revenue from activities in Germany and exclusively focus on the energy supply system as their market. Energy technology and materials firms tend to be more diversified in terms of geography as well as customer market. Hence German policies and changes to the German energy system affect the lower part of the energy technology value chain in their entire business, and the upper part of the energy technology value chain only in a certain part. This means that the innovation activities of the latter are only to some extent influenced by German policies. Especially the large, diversified energy technology and materials firms have emphasized that any change to the energy system in Germany is only relevant to the extent of its share in the global activities of the firm.

Lastly, the different value chain positions have exhibited differences in the time it took them to react to the changes in their business environment. Overall, firms in energy technology and materials were faster to react and adjust their innovation activities than electricity suppliers and grid operators. All firms were equally observant of the market and claim to have seen changes and policies affecting their business activities early on. However, especially in renewables (cf. section 6.2.1.1) and energy efficiency (cf. section 6.2.1.3) it seems that energy technology and materials firms were always few years ahead of electricity suppliers. Since these upstream firms tend to provide the technology that is used by their downstream customers this is not entirely a surprise. Furthermore, for energy technology and materials firms, innovation is a more deeply engrained part of their business as they operate in sectors that continuously evolve, whereas the electricity supply sector had prior to the changes induced by the energy transition been stagnating for decades. However, energy technology and materials firm tended to be more skeptical of market demand existing purely because of regulatory reasons, fearing that the demand was not sustainable enough to justify investments in innovation activities.

Value chain position mediates the effect of the Energiewende policy mix because especially because firms are in a different strategic and structural set-up and because they possess different resources and capabilities. Similar findings have been made by other scholars who have contrasted and compared these value chain steps or specifically investigated one or the other (Rogge, Schneider, et al., 2011; Voß et al., 2003). Nevertheless, the lower as well as the upper part of the value chain have equally sought innovation activities in line with their resources and capabilities and exhibited similar biased towards an energy system based exclusively on renewable energy, see section 6.4.2.3 below.

6.4.2.2 Industry position

The case studies show that the industry positions of the firms surveyed i.e. if they are incumbents or start-ups in their respective sectors did in certain aspects also bear on innovation activities. Unsurprisingly, start-ups proved to be more dynamic and faster to react to changes than incumbent firms in their respective value chain steps and sectors. Also, start-ups challenged the status quo of technologies, business models and power structures in the energy technology value chain on various occasions.

Start-up energy technology firms played a critical part in the exploration, development, and implementation of technologies for electricity generation from renewable energy sources (cf. section 6.2.1.1). When incumbent energy technology firms discontinued or decreased their activities due to their expectations of a slow market, start-up energy technology firms continued to invest and keep the technology alive throughout the 1980s and 1990s. To no surprise did many become popular take-over targets of large incumbents when their interest in renewable technology reignited in the early 2000s.

Start-up electricity suppliers disrupted their industry with asset-light business models that did not rely on the ownership and operation of generation capacity (cf. section 6.2.3.5.1). Turning electricity from an undifferentiated commodity into a branded product they fundamentally changed the outlook of the sector.

In contrast, incumbent firms in the upstream and downstream parts of the value chain had to change their established businesses and often catch up with start-ups. Innovation activities that were in the course of the case studies only discussed for incumbents were the adoption of energy-efficient technologies and materials for the modernization of their operations (cf. section 6.2.2.2), the articulation of pro-environmental visions and strategies (cf. section 6.2.3.1), the creation of organizational departments to focus on innovation and other activities relevant in the context of Energiewende (cf. section 6.2.3.2) and the initiation of cultural change processes to make their organizations fit for a new energy system (cf. section 6.2.3.3.).

Industry position hence mediated the effect of the Energiewende policy mix. While incumbents were affected in their established business and had to make adjustments, for start-ups the markets created through Energiewende often constituted the basis to begin their activities in the first place (cf. sections 6.2.1.1.1, 6.2.1.3.2, and 6.2.3.5.1). However, once established, they were subject to the same dynamics and influences as incumbent firms.

6.4.2.3 Resources, capabilities and cognition

Across value chain positions and industry positions, the resources, capabilities and cognition of the firms influenced the direction and timing of the innovation activities carried out.

Throughout the case studies, the surveyed firms stressed that they mostly sought activities complementary to their assets and capabilities. Complementarity was a key consideration for the decision to start exploring new technologies or activities in many areas (cf. sections 6.2.1.1.2, 6.2.1.2, 6.2.1.3.2, 6.2.1.4.2, 6.2.2.1 and 6.2.3.5.2) as well as to engage in collaborations (cf. section 6.2.3.4). For example, when discussing how to enter the market for renewable energy, incumbent energy technology firms thought it easier to go into wind, off-shore wind in particular, due to the comparatively large generation capacity per power plant and the capital and project management experience required to construct these plants, all resources and capabilities these firms thought to possess.

In addition, corporate cognition i.e. the "dominant logic" (Tripsas & Gavetti, 2000) of how things work in the firm, industry, and system also played a major role. Corporate cognition influenced the way that firms interpreted the Energiewende policy mix and shaped their reaction to it in terms of innovation activities. Strikingly, across firms from all value chain and industry positions, only with the exception of a few start-ups, firms adhered to the idea that an energy system built on the supply of energy from large, central, and continuous energy sources was inherently superior to one built on small, decentral, and fluctuating ones. Two nuances of this bias existed. The first nuance held that such a system would deliver better results for the energy system in terms of costs and security of supply, the second nuance held that electricity supply worked best in a vertically integrated value chain with electricity suppliers controlling the provision of electricity from the construction of power plants to distribution to end consumers. Clearly these biases disadvantage renewable energy sources in comparison to fossil and nuclear energy sources and imply an assessment of the energy system predominantly in terms of efficiency and reliability, which indeed were the important criteria before environmental concerns started to emerge. They hence reinforce the energy system that prevailed before the energy transition started.

The first nuance of this bias prevented an earlier adoption of RES-E generation capacity among incumbent electricity suppliers as they turned a blind eye on the growing installations (cf. section 6.2.2.1). The same cognitive bias also prevented earlier larger scale investments into developing energy technology for RES-E generation on the parts of incumbent energy technology firms (cf. section 6.2.1.1). The second nuance of biases increased the difficulty of cultural change (cf. section 6.2.3.3) and business model innovation (cf. section 6.2.3.5). Strikingly though, at least in parts start-ups admit to the same biases as incumbent firms (cf. section 6.2.3.5.1).

The case studies also show that firms are within their own organizations not necessarily united when it comes to their biases. While similar biases tend to prevail in one organization, there may be intra-organizational differences. The bias within a firm is not uniform. Individual units or members of these organizations had weaker biases and consequently pushed for more or different innovation activities. They may have advocated a faster adjustment of their organization to the changing energy system and thus promoted the transition of the energy system itself. Senior management plays a critical role as it defines the strategic path for a firm and determines whether it reinforces or seeks to break cognitive biases (cf. section 6.2.3.3).

In a slightly different way, there was also a positive cognitive bias in terms of a vision for a world without fossil and nuclear energy sources that drove the innovation activities of some firms, most importantly start-up energy technology firms in the renewables industry. These firms strived towards an ideal even at a time where the market alone did not provide a strong case for investments into exploration, development and implementation of RES technology (cf. sections 6.2.1.1.1 and 6.2.3.5.1).

For incumbent electricity suppliers, this bias even persisted when renewable energy started to grow exponentially and the market potential was not doubted anymore. It is hard to say when this cognition started to change and possibly fair to say that a change may still be under way. Incumbent electricity suppliers typically state the energy policy decisions for accelerated nuclear exit with equally ambitious environmental targets following Fukushima as the point where it became final, that an overhaul of the system was inevitable (cf. section 6.3.1).

The impact of firms in the light of resources, capabilities and cognition will be further discussed in the next chapter (cf. section 7.1.3).

6.4.3 Synopsis: impact of confounding factors

This section has discussed the impact of confounding factors on the development of innovation activities and innovation dynamics. Context factors, i.e. factors from firm's external business environment, were considered along with firm characteristics, i.e. structural aspects and organizational factors internal to the firm. The discussion shows that these factors interact with the effect of the German Energiewende policy mix on innovation activities in three ways. First, they can have an effect on innovation activities independent of the policy mix, second, they can themselves be influenced by the policy mix and hence mediate its impact on innovation activities, third, they can strengthen or weaken the effect of the policy mix and fourth, they can in turn influence the components in the policy mix. Unsurprisingly due to the interrelatedness and co-evolution inherent in a complex transformation, many of the factors do more than one thing over time.

As for context factors, the market and industry dynamics identified were crucial drivers of innovation activity, especially independent from the Energiewende policy mix or as mediators of the effect of demand-pull instruments. Risks to the supply of fossil energy sources and the demand for energy from renewable sources (RES) drove the exploration, development and implementation of RES technology. The demand for solutions for an RES-based energy system drove innovation activities in smart grid, energy management and energy storage. The expectation of high energy prices was a motivation for activities regarding energy efficiency. Low wholesale electricity prices fostered business model innovation. However, some of these factors, especially the demand for energy from RES and the low electricity prices were effects of the German Energiewende policy mix. In addition to market factors, environmental policy in other countries, in the EU or on a multilateral level, also had an independent effect on innovation activities and in parts constituted antecedents to German Energiewende policy. Landscape developments such as digitalization and environmentalism had an independent effect, but also strengthened the effect of the

Energiewende policy mix and, moreover, environmentalism contributed towards its emergence in the first place.

Firm characteristics mainly influenced to what degree and how the Energiewende policy mix had an effect on the innovation activities of firms. With regards to value chain position, electricity suppliers were overall more affected by the Energiewende policy mix than energy technology firms, but slower to react. With regards to industry position, incumbents were disrupted in their usual way of doing business, start-ups were often only established because of market opportunities that presented themselves as the result of the Energiewende policy mix. Lastly, resources, capabilities and cognition strengthened or weakened the effect of the Energiewende policy mix. Firms embraced Energiewende relevant innovation activities especially when their assets and capabilities were considered complementary with the area or requirements of the innovation activities. However, this also meant that some areas were avoided. Furthermore, cognitive biases towards an energy system relying on conventional large-scale electricity generation delayed innovation activities for a new, RES-based energy system.

7 Extended analysis and discussion

After the detailed presentation of the case study findings in the previous chapter, this chapter turns to more extended discussions and implications from the empirical research conducted. This chapter addresses the third research interest to draw implications for political and corporate actors through answers to controversies in the existing literature, the identification of tensions, and making recommendation to policy makers and firms.

Earlier in this thesis (cf. section 4.3) three controversies regarding the impact of the German energy transition on innovation were pointed out: first, if and to what extent the EEG had an effect on innovation, second, to what extent the accelerated energy transition post-Fukushima affected innovation and third, to what extent the energy transition triggered changes within firms. The controversies are reflected in light of the case study findings and integrating knowledge from the relevant literature (cf. sections 2.2 and 5). In addition to these controversies a couple of tensions emerged throughout the case studies: Inconsistencies between political strategy and systemic regulation, the difficulty of providing incentives without leading to opportunism, and the limited effectiveness of policies confined to national jurisdictions have challenged innovation activities. Drawing on the case study findings as well as the controversies and tensions, recommendations for policy makers and firms for innovation in the context of socio-technical transitions towards sustainability can be derived.

This chapter is organized as follows. First, the three controversies will be revisited. Second, the three tensions that emerged recurrently throughout the analysis of the case studies are elaborated. Third, implications for politics and companies are drawn.

7.1 Revisiting the three controversies regarding the impact of Energiewende on innovation

7.1.1 Effect of the Renewable Energy Research Act (EEG)

The first controversy pertains to if and to what extent the EEG had a positive effect on innovation in the sense of exploration, development and implementation. Two groups of researchers, first, the federal government's expert commission for research and innovation (EFI), and second, researchers around the Center for European Economic Research (ZEW) come to opposing conclusions in this question. The first group maintains that the EEG did not have a positive effect as it did not increase patent applications in technologies for electricity generation from renewable energy (RES-E) (Böhringer et al., 2014; EFI, 2014; Frondel et al., 2010). The second group argues that the EEG had a positive and far-reaching effect on innovation as it drove cost-reductions and performance improvements in RES-E technology, and in addition spurred innovation in complementary technologies and organizational and institutional novelties (Ragwitz et al., 2014; Rennings & Rexhäuser, 2014).

The empirical findings of this thesis provide evidence to support the views of the second group. The case studies show that the EEG is the single most important policy of the German Energiewende policy mix and is widely known and recognized as the core policy element of the energy transition. It had a direct positive effect on innovation in the sense of the adoption of RES-E technology, but also several indirect, dynamic positive effects on the exploration, development and implementation of novelties in complementary technologies and systemic solutions. The dynamic effects span technological and organizational changes. Furthermore, it is important to recognize the EEG not only for its feed-in tariff, which the discussion typically tends to do, but also for the design features that contributed to a transition of the energy system. At least five ways in which the EEG has affected innovation activities can be identified.

First, the feed-in tariff and preferential grid access for RES-E installed by the EEG 2000 had a direct effect on innovation in the sense of adoption of RES-E technology. Many of the firms studied installed RES-E technology in order to profit from the guaranteed feed-in-tariff rates. However, only a small fraction of the RES-E capacity installed in Germany was actually owned and operated by incumbent electricity suppliers (Geels et al., 2016) because the return on investment offered by the EEG was more attractive to private and new corporate investors than to the electricity supply incumbents. The diffusion of RES-E technology was hence primarily through the actions of niche actors, which were enabled by the specific design features of the EEG that, first, provided an attractive return to smaller investors and second, guaranteed preferential grid access to ensure that this return could be realized (Geels et al., 2016). It was only since the mid 2000s that incumbent electricity suppliers got serious about the installation of RES-based generation capacity and then used the EEG to boost the profitability of their German renewable generation assets (cf. section 6.2.2.1).

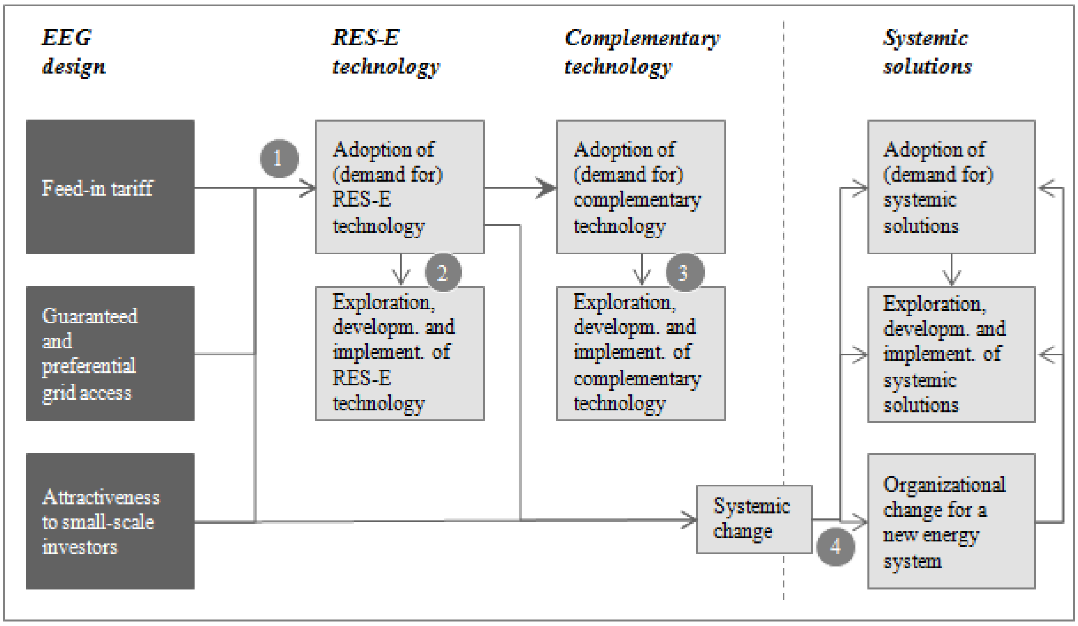
Second, the above mentioned provisions of the EEG 2000 had an indirect positive effect on innovation as the increased demand for RES-E technology provided energy technology firms with a rationale to invest in the exploration, development and implementation of technological improvements and cost reductions for RES-E technology. Incumbent and start-up energy technology firms entered the market for RES-E technology and increased their investments into activities leading to technological improvement and cost reduction against the background of the increased market potential. The case studies have explored this effect across the range of RES-E technologies, however, with a particular focus on solar energy (cf. section 6.2.1.1.2).

Third, the adoption of RES-based generation technology also contributed to the adoption, and consequentially also the further development of technologies directly complementary to RES deployment, especially power lines and other physical technology for the expansion of distribution and transmission grids to be able to take on the renewable electricity generated in decentral locations (cf. section 6.2.2.3).

Fourth, the EEG had a further indirect, dynamic effect on innovation as it provided for a transition of the energy system as a whole. The increase in RES-E installed capacity, electricity generation, and share of RES in the electricity mix created the need for solutions for an RES-based energy system and consequently triggered exploration, development and implementation in systemic solutions such as smart grid, energy management, and energy storage. The case studies show that issues resulting from a rising absolute and relative amount of RES-E in the Germany energy system were important motivations for firms to start developing such solutions. Especially as the developments set off by the EEG took on a systemic dimension i.e. challenged the stability of the electricity grid, shifted the geographical distribution of electricity generation capacity, and enabled new players in the energy system, the need for solutions became apparent. As "need" signifies a market demand and this in turn signifies earnings potential, corporate actors were motivated to react and find solutions through innovation activities. The effect of the EEG hence multiplied beyond electricity generation and RES-E to several other areas such as smart grid, energy management and energy storage, triggering proper "innovation cascades" (Berkers & Geels, 2011) where knock-on effects and second-order learning processes lead to a reconfiguration of a systemic architecture (Geels et al., 2016). The significance of this development is also exemplified by incumbent firms fearing new competitors from other industries in the energy technology value chain (cf. section 6.4.1.1). Figure 23 summarizes the four innovation effects just described by depicting important design features of the EEG and their dynamic influence on innovation in RES-E technology, complementary technology, and systemic solutions.

Fifth, albeit the majority of the discussion around the EEG revolves around the EEG 2000, also provisions of the later amendments to the EEG did also bear on innovation activities. For example, the provision for the direct marketing of RES-E introduced by the EEG 2012 amendment created the demand for electricity market access for owners of RES-E generation capacity and hence motivated firms, in particular incumbent and start-up electricity suppliers, to develop and implement service offerings and business models to that end (cf. sections 6.2.1.4.2 and 6.2.3.5.2).

Figure 23: Innovation dynamics triggered by the EEG 2000



The controversy in the literature is due to an often narrow understanding and focus only on the second effect. Moreover, in the investigation of the second effect innovation is measured in a narrow way and a linear and timely influence of political provisions is assumed. This is done first, by focusing only on patent counts, which are an incomplete and imperfect representation of innovation as elaborated elsewhere (Del Río González, 2009; Griliches, 1990), and second, by seeking to infer a direct effect of feed-in tariffs on exploration, development and implementation when the actual effect is indirect via the market demand created by adoption, and also not linear given the structural, strategic and cognitive barriers that were identified in the case studies and that interfere with innovation activities (cf. section 6.4.2.3 in findings and discussion in section 7.1.3).

For the environmental innovations literature the findings of the case studies suggest that in addition to exploring the effect of demand-pull policies on technological innovation in the specific area targeted by the demand-pull policies, it may be a viable path to investigate effects in complementary technologies that were not targeted by the demand-pull policy, as well as non-technological innovation and innovation in systemic solutions. Previous empirical investigations have especially provided evidence for an effect in the same technology area that was targeted by the demand-pull policy, e.g., an effect on innovation in RES-E technology after the installation of RES-E deployment schemes (Johnstone et al., 2010; Wangler, 2012). However, to get a more complete picture of the innovation effect, innovation in adjacent technologies, non-technological and systemic innovation should be considered, a fact that is already recognized in the literature (Del Río González, 2009; Rennings, 2000). In the context of the energy transition this applies to e.g., innovation in energy storage technology (complementing electricity from solar PV), the organizational changes within firms, and the attempts to introducing new elements such as supply and demand management to the electricity system as a whole. Furthermore, using insights from actors in innovation as to why innovation activities occur and what the barriers are is also fruitful. Lastly, the case of the EEG illustrates once more that in addition to the elements of a policy, its design features are also critical.

The EEG presented a simple logic that provided investors from outside the incumbent electricity supply sector with an attractive, zero risk investment opportunity. It was almost reckless in its ambition to increase electricity generation from renewables, empower small scale electricity producers and in this way change the energy system. This recklessness, however, proved to be essential to increasing RES-E to the extent done and consequently changing the energy system.

Looking into the future it remains to be seen whether the EEG will continue to drive innovation to the same extent that it has done in the past. In the 2016/2017 amendment of the EEG a paradigm shift to the promotion of RES-E was introduced by replacing support tariffs determined by policy makers with payments determined through an auctioning mechanism. Prospective investors bid for the rate that they require to install RES-based generation capacity and bids get accepted from low to high until the additional capacity requirements planned by the federal government are fulfilled (cf. section 3.3.4). This may have implications for the ability of the EEG to fuel innovation in the way it has done in the past.

On the positive side, the expectation is that auctions will lead to lower subsidy rates than those set by regulators as competitive pressure forces prospective investors to bid as low as possible to secure a winning bid. In order to be able to bid low they will adopt the most cost-efficient technology as soon as it becomes available and hence contribute to the diffusion of such technology. Cost reductions due to technological improvements will be reflected in auctions without the delay that comes with the regulatory review of previously set tariff rates. Slimmer margins due to reduced subsidy levels may also induce investors into RES-E capacity to get more innovative around their other sources of income and e.g., improve their direct marketing capabilities or combine their RES-E capacity with more sophisticated energy management and energy storage in order to be able to maximize the value of their capacity installations. As the market premium is paid out as the difference between the average spot price for electricity in a given month and the successful bid price, every price realized above the average spot price is additional income. Furthermore, to encourage novel applications of RES-E generation technology in combination with systemic elements, the 2016/17 EEG provides for so-called innovation tenders (*Innovationssausschreibungen*) to be held for a certain amount of capacity. Contenders in these auctions will need to combine RES-E generation technology with elements that support the wider energy system and grid network and contribute to an integration of the three energy forms electricity, heating and transport (*Sektorkopplung*). Details of these are, however, yet to be worked out in 2017 and 2018 (BEE e.V., 2016a). These dynamics could also constitute a positive impulse for innovation in terms of exploration, development and implementation of novel solutions for combined applications of RES-E technology as well as organizational change, in particular new business models.

On the other side, however, the cost pressures introduced through auctions may reduce the willingness and capacity to experiment with new technologies that are more costly in the short term, but may prove beneficial in the long run. Furthermore, an auctioning system is more complex and more costly to administer for prospective investors than the compelling, simple process of guaranteed feed-in tariffs that marked the EEG since its beginnings. Significant upfront investments in terms of planning a project, pricing it and participating in the auction are required while there is a significant risk of not securing a winning bid and hence losing out completely. Smaller actors that do not have the knowledge and resources to compete in an auction will be disadvantaged. The EEG amendment seeks to prevent this by granting energy cooperatives (*Bürgerenergiegesellschaften*) easier access to the auctions, but it remains to be seen whether this will be sufficiently effective. From the outset, larger, more capital-intensive player will have an advantage. Given that the dynamics introduced by new, emerging players in the electricity system greatly helped to foster innovation activities in the context of Energiewende this is worrying. The growth in capacity additions may also be slower than before since the time needed for the auctioning process will come on top of the time needed for financial and technical planning and obtaining permissions (BEE e.V., 2016a). If this means that the anticipated growth pathway cannot be sustained it significantly lowers the attractiveness of the RES-E market and hence adversely affects innovation activities in the technological as well as non-technological sphere.

The EEG 2016/17 is not overwhelmingly negative for innovation activities in RES-E and may even give some new, positive impulses. It is not likely that the amendment will stall innovation overall since the market has grown to a sufficient size, the system has already fundamentally changed, and there is the clear expectation that RES-E capacity will continue to be added until the 2050 targets of the Energy Concept are reached. The fundamental basis for competition and innovation hence remains intact. However, the EEG 2016/17 will decrease the dynamism and cement a mature state with steady, but lower growth. It certainly does not create much opportunity space to disrupt going forward.

7.1.2 Effect of the accelerated energy transition post-Fukushima

The second controversy revolves around the extent to which the so-called "accelerated energy transition" that was proclaimed by the federal government in 2011 following the Fukushima nuclear incident had an additional positive effect on innovation. The federal government and some researchers proclaim this view, especially for the electricity supply industry (BMWi, 2012a; Bontrup & Marquardt, 2015; Kungl, 2015; Strunz, 2014). Other researchers do not attribute specific importance to 2011 in terms of innovation (Böhringer et al., 2014; EFI, 2014; Geels et al., 2016).

The empirical findings of this thesis provide a differentiated perspective on the significance of the accelerated Energiewende for the innovation activities of firms that is in the middle between the two controversial poles. The findings of this thesis support the hypothesis that the political decisions of 2011 finalized the shift from a fossil-nuclear to an RES-based energy system, however, it had a disruptive effect only on the activities of electricity suppliers, not of energy technology and materials firms. The accelerated energy transition that was proclaimed after Fukushima increased the change dynamics and the urgency with which innovation activities supporting Energiewende were carried out across all sectors. Firms stated repeatedly that topics relevant to the energy transition gained more senior attention and found it easier to get company internal resources (cf. section 6.3.1). For energy technology and materials firms, however, 2011 did not lead to a change of the principal direction of innovation activities. Significant strategic changes had been made before (cf. section 6.2.3.1) and innovation activities across a variety of areas relevant to the energy transition initiated (cf. section 6.2.1). Given the mostly global activities in the sector the decisions in Germany did not have strong enough impact to change the overall direction. Merely adjustments at the margin such as re-locating nuclear research activities or further pursuing nuclear divestments took place. For electricity supplier, however, the accelerated energy transition constituted the final realization that a systemic change of the energy system was inevitable and catalyzed their search for new business models. Write downs on nuclear generation assets and the decreasing wholesale electricity prices that diminished the returns of conventional generation portfolios drove the need for action (cf. section 6.2.3.5.3). Having no other market than Germany to diver to, the impact of 2011 on electricity suppliers was hence far more substantial than the effect on energy technology firms.

7.1.3 Effect within incumbent firms

The third controversy concerns the extent to which Energiewende has triggered changes within incumbent firms. There are a couple of investigations on incumbent electricity suppliers claiming that they reacted too late to Energiewende, but offering opposing explanations for this behavior. One explanation puts this delayed reaction on corporate inertia and complacency in general (Bontrup & Marquardt, 2015), another one holds it to be a deliberate strategic decision intended to avert a profound change of the energy system (Kungl, 2015). Both position incumbent firms as regime actors of the old, fossil-nuclear based energy system. However, none of these publications has directly studied members of the firms in question. Furthermore, they are exclusively focused on electricity suppliers.

The findings of the empirical investigation in this thesis provide a middle ground between the two, but critically expand the understanding of this controversy through the insider's perspective gained in the case study interviews with managers of firms of the entire energy technology value chain. Three findings advance the current understanding of the role of firms in the German energy transition: First, not only incumbent electricity suppliers, but also energy technology firms struggled to embrace renewable energy sources and pursue the respective innovation activities. Second, strategic, structural as well as organizational factors influenced this behavior on part of the incumbents, although the cognitive bias towards a fossil-nuclear energy system may have been the most important one. Third, the way that change unfolded on the level of individual firms shows that firms are not unitary in their beliefs and actions, but that niche-regime struggles that can be observed on a societal level can also found within individual firms.

First, all incumbent firms in the energy technology value chain fundamentally struggled with RES technology and suffered from similar barriers to change. Contributions on technological change and the energy transition in Germany tend to focus on the electricity supply industry i.e. only the downstream part of the energy technology value chain (cf. Bontrup & Marquardt, 2015; Fuchs, Hinderer, Kungl, & Neukirch, 2012; Geels et al., 2016; Kungl, 2015). Electricity suppliers clearly are more profoundly affected by the systemic changes and have more fiercely defended the fossil-nuclear system (cf. section 6.4.2.1). However, incumbents of all value chain steps surveyed in the case studies agreed that they did not anticipate such a fundamental change to the energy system to occur over such a short period of time and admitted difficulties in finding the appropriate response for an RES-based, decentral energy system.

Second, structural, strategic and organizational reasons are important to explain the behavior of incumbent firms. When it comes to RES technologies, the case studies find that it took all incumbent firms very long to embrace them. This was partially due to the structural and strategic conditions provided by past decisions and the respective value chain positions, e.g., the perception that the market for RES was too small or the commitment to customers who were focused on conventional energy sources (cf. section 6.4.2.1). A deliberate decision to prevent systemic change was not brought forward in the case studies. It was also the perception that company resources and capabilities were better aligned with fossil-nuclear energy technology than with technology for RES. However, underlying this was a cognitive bias towards a fossil-nuclear energy system that was shared by all incumbents studied (cf. section 6.4.2.3). The dominant logic (Prahalad & Bettis, 1986; Tripsas & Gavetti, 2000) of the incumbent firms was that an energy system with energy supply from central and stable energy sources was inherently superior to an RES-based system relying on decentral and fluctuating energy sources. Other technologies in the context of Energiewende such as energy efficiency were not subject to the same bias, but faced a more rational cost-benefit analysis. This logic was shared across firms of the energy technology value chain, implying that it constitutes not only the dominant logic of these individuals or firms, but also regimes in the sense of the multi-level perspective i.e. semi-coherent sets of rules that are shared by a group of actors within a system (Geels, 2004).

The dominant logic or rules of the regime determined how the incumbent firms of the fossil-nuclear based energy system noticed, interpreted and acted upon external developments. Challenges to these beliefs as they emerged over time from environmental movements in the 1970s, renewable energy technology start-up firms, and then increasingly also from policy makers, first timidly with R&D budgets for the exploration of alternative energy sources, then forcefully with the strong endorsement of renewable energy and the nuclear exit of 2000, were considered illogical. As a result, the activities started by incumbent firms as responses had at best the objective to explore these alternative views and determine their business potential. Especially in the beginning of the energy transition in the 1990s and early 2000s, however, they were primarily initiated to appease public opinion, convey the impression of being a responsible corporate citizen to policy makers, or opportunistically utilize the financial incentives provided (cf. section 6.2.1.1). Early reactions, especially by electricity suppliers, were rarely considered strategic, business-driven and consequently did not result in the profound strategic and organizational changes required to ensure their long-term implementation. The dominant logic and cognitive bias hence significantly contributed to maintaining and defending the status quo instead of exploring new ways or giving alternative options a chance. Because of the cognitive contingencies that had over time resulted in strategic, structural and organizational ones, the firms as a whole did very long not realize that there was a potential for an entirely new system to emerge and did not position themselves for it.

Third, the struggle of the energy system to transform was mirrored within its incumbent firms. When changes within firms in the energy technology value chain started to take place, they exposed similarities to the niche-regime struggles observed on the systemic level.

It is typical in the multi-level perspective to analyze systemic changes through the interactions of landscape, regime and niche. Actors are often associated with either niche or regime and hence seen as niche or regime players. Consequently, a transition through the emergence of niche players that overtake and replace regime players is a frequent illustration of a transition pathway (Geels et al., 2016; Geels & Schot, 2007). The failure and demise of incumbent firms in the light of disruptive technological change is also a feature in the organization and management literature (cf. section 2.2.3.2). However, the literature has also increasingly realized that firms can survive technological change processes or even enact these change processes from within. The solution is seen in the right balance of the exploration and the exploitation method to organizational learning (March, 1991), an art that when mastered is also called ambidexterity (O'Reilly & Tushman, 2008, 2013).

The notion of the combination of two methods of learning in one firm suggests that firms are no unitary actors, but can be internally divided. The case studies here show that within firms of one group, and even within one firm, differences exist. Firms, especially large ones, are heterogeneous organizations made up of several units and many individuals whose opinions, albeit having the tendency to revolve around a dominant logic, may still diverge (Tripsas & Gavetti, 2000). The semi-coherence of rules of the regime that the MLP notes between actors hence also exists within actors. This opens up the possibility to suggest that firms themselves go through a transition. Individuals or organizational units within firms can constitute niches and promote change. As a consequence, the transition pathways and patterns typically used by the MLP to describe systemic transitions (cf. section 2.2.1.2.4) may also be found in individual firms.

On a systemic level, Geels et al. (2016) frame the transition of fossil-nuclear electricity generation to RES-based electricity generation in Germany fundamentally as a substitution pathway hence holding that new entrants replace the main electricity producers of the old regime. For some of the large incumbent electricity suppliers internally, however, it looks like an attempted and failed transformation pathway shifted to de-alignment. When they started to consider changes, electricity suppliers worked on a transformation where they tried to fit RES niche technologies into their established business (cf. sections 6.2.1.1 and 6.2.2.1). They partially succeeded when they expanded their innovation activities regarding RES and even established RES business units (cf. section 6.2.3.2), however, never fully overcame their own bias regarding the superiority of a conventional central energy system. The external shock from declining electricity prices and the post-Fukushima accelerated energy transition disrupted this pathway. The surge in business model experimentation that occurred after 2011 can more suitable be framed in terms of a de-alignment pathway as the regime (exemplified by the conventional business model) is destabilized beyond the point of repair and collapses as a consequence (Geels & Schot, 2007, p. 408).

The split-up of the largest German national electricity providers E.ON and RWE illustrates this de-alignment. E.ON announced the carve-out of its fossil-fired power plants in a new legal entity under the brand *Uniper* in late 2014. The E.ON parent retains all activities related to renewable energy, electricity grids, end customer solutions, and, after political and public pressure, also the nuclear assets (E.ON SE, 2016). RWE followed suit in 2015, but took another route by placing its renewable energy, electricity grid and end consumer activities in the separate entity *Innogy* while conventional assets incl. nuclear remain with RWE (RWE AG, 2016). Both transactions were completed with the listing of the new entities on the German stock exchange in fall of 2016 and operate separately from their parent firms. RWE, at least for now, retains majority ownership of Innogy while E.ON has floated more than 50% of Uniper. Both firms explain their split-ups with the fundamental differences between the conventional and new business models in the electricity sector and as a consequence the inability of capital markets to correctly value firms that engage in both (Chazan, 2016). The divisions furthermore illustrate a de-alignment pathway and how firms are no unitary actors, but can combine a variety of different, even opposing, cognitions, interests, and strategies – at least until a certain point. Clearly the transition here is still ongoing and a re-alignment of the sector has not occurred yet. Instead the exploration of new business models continues and is marked by the "prolonged period of co-existence, uncertainty, experimentation and competition for attention and resources" (Geels & Schot, 2007, p. 408) that defines a de-alignment/re-alignment pathway. Incumbent electricity suppliers are still searching for their business models for the coming decades.

In contrast to this, the transition of incumbent energy technology firms towards RES technology appears to be a successful transformation pathway for the most part where they – after overcoming their cognitive bias – integrated niche technologies into their established way of doing business (cf. section 6.2.1.1.2). The sources of niche activities within firms seem to stem from dedicated search efforts and innovation departments as well as leadership. Energy technology firms are used to navigating a volatile business environment and therefore have dedicated departments for innovation that monitor technological change and other disruptive influences. The activities of these departments provided the internal niche where ideas could develop and grow before being implemented in usual corporate activity (cf. section 6.2.3.2). Leadership played a role as well (cf. section 6.2.3.3). CEO agendas shaped innovation strategies and mandated the reorganization of business units. The profound strategic and organizational change could not have been initiated by other hierarchical level. Energy technology firms were hence better than electricity suppliers when it came to exploration and exploitation at the same time.

7.2 Tensions in the policy mix impeding innovation activities

7.2.1 Innovative political strategy versus path dependent systemic regulation

The case studies show tensions or inconsistencies between the articulated Energiewende vision and strategy and some of the systemic regulations governing the energy system. In their conceptualization of policy mixes for environmental change, Rogge & Reichardt define consistency as the "absence of contradictions" or the "existence of synergies within and between the elements of the policy mix, thereby enabling the achievement of policy objectives" (2013, p. 23). The case studies find inconsistencies between the political objective to change the energy system towards being exclusively RES-based and systemic regulation that impedes or inhibits innovation for enablers of such an energy system, especially when it comes to smart grid, energy management and energy storage.

During the case studies barriers to the market and grid integration of demand side management and electricity from storage were explicitly identified (cf. section 6.2.1.5.1and 6.3.2.3.3). Rules and regulations for the governance of the energy system have limited more profound changes to the system such as new actors, new nodes or new ways of earning revenue in these areas (cf. 6.3.2.3.3). Moreover, the inconsistencies identified are probably not the only ones. Agora Energiewende, a think tank that devises political and economic strategies for the energy transition, continuously points out legal and regulatory barriers on very detailed granular levels in its studies on how to advance Energiewende. For example, a study identifies multiple and complex regulatory and market price barriers explaining the slow development of load management as a supply side energy management approach (Connect Energy Economics, 2015). Furthermore, also the use of power-to-heat to store and thus utilize RES-E instead of decrease production in times of physical grid restraints is limited by regulatory barriers (Gerhardt et al., 2014).

Parts of the systemic regulation still seem to embody the rules of the regime (Geels, 2004) applicable in a fossil-nuclear based energy system. Such rules have found to exhibit a high degree of path dependence and resistance to change. Administrative, legal and grid access can constitute "non-economic barriers" (Klessmann et al., 2011, p. 7651) in an energy transition. In this case they prevent a transformation and optimization of the system as a whole that could address the problems of volatility of energy supply that is inherent in the deployment of renewable energy sources. Lockwood (2016) makes similar observations regarding the regulatory framework of the electricity distribution network in the UK and its introduction of smart grids. The discussion of the impact of systemic regulation here is by no means as detailed as the one prepared by Lockwood, however, the findings point in the same direction. The rules and regulations of the energy system exhibit a dual force that provide for systemic change in some areas and with some mechanisms, but also restrict change in other areas through other mechanisms.

7.2.2 Strong short term incentives versus long term orientation

The case studies show that in their innovation activities firms notice and react to incentives set by politics. These can be the incentives of technology-push policies where research activities or the adoption of new technology is directly subsidized by public funds, the incentives of demand-pull policies where e.g., subsidies lead to market growth that lures firms to enter the market, or the incentives of systemic regulation if it is set in such a way that it strongly affects business opportunities. The case studies have found hints for instances of opportunistic behavior on parts of firms faced with such incentives. This was for example the case for demand-pull instruments, e.g., when policy induced market growth led to questionable behavior of energy technology start-ups in the solar PV industry (cf. section 6.3.2.2.3). The notion that firms jump into markets such as energy efficiency as they are created by policy makers points in that direction (cf. section 6.2.3.5.2). Also the descriptions by incumbent firms of how, in the early days of the energy transition, they used public funds for research projects they did not believe in, possibly even with the intention to prove technologies unworthy, exhibits similar tendencies (cf. section 6.2.1.1.1). The flip side of such incentives is that firms can be distrustful of them to a point that they contemplate market entry all together (cf. sections 6.3.2.2.3).

The finding that strong incentives can lead to opportunistic behavior that impedes innovation activities and transition processes is not new do the literature. For the global solar PV industry, Hoppmann et al. (2013) show that while policy-induced market growth in general leads to technological exploration in the form of R&D investments, it can also increase the relative strength of exploitation i.e. investment in production capacity in relation to exploration. This is not necessarily bad or undesirable. However, if technological improvement is the objective, one does not want the exploration for such improvements to diminish too much. Policy-induced market growth can hence be a double-edged sword for innovation activities. In more general terms such opportunistic behavior is also called *rent-seeking* and comes as a side-effect of almost all political intervention in a market. It is widely recognized and studied, both in its general implications for the economy as well as specifically for the obstacles it can constitute for innovation (Buchanan, Tollison, & Tullock, 1980; Krueger, 1974; Murphy, Shleifer, & Vishny, 1993).

Nevertheless, it has been equally established that political intervention in the realm of environmental innovation is necessary (cf. section 2.2.2), and the case studies have shown that the Energiewende policy mix did indeed foster innovation activities in various ways. Opportunistic behavior is to a certain extent a phenomenon that has to be reckoned with and cannot be entirely eliminated. Also, there is nothing to indicate that this has been a major problem of the German Energiewende so far, nothing that has impeded technological progress or the transition of the energy system. Overall many firms, especially from the allegedly opportunistic solar PV manufacturers, stress their idealistic motivation for an energy transition towards renewables, the direct opposite pole to opportunism (cf. section 6.2.1.1.1). A tension only arises when incentives are so short-term that they can be opportunistically exploited without actually stimulating innovation activities that are required for a transition in the longer term. Irrespective of type of incentive, this behavior occurs when market participants regard the long term market potential as insufficient to justify corporate activity beyond exploiting the incentive. Nevertheless, in the context of a transition incentives are justified if they encourage a particular desirable behavior that has the potential to have a long run impact in favor of this transition. In this way incentives are fundamentally a measure of niche protection. To ensure that incentives work in that way they have to be monitored in size, perception of longevity, and market fundamentals behind them. In the light of this tension the effect of political intervention on the incentive of actors needs to be monitored.

7.2.3 National political jurisdiction versus international firms

A third tension that has emerged in the case studies is the limitation of national political jurisdictions in the light of international firms. The limitation of national politics to induce innovation when firms have a global orientation has been noted several times throughout the case studies. Firms have emphasized that in their assessment of market potential, on which they base their innovation decisions, it is the global market that counts rather than the German one. This means that German politics influences these firms only to the extent that Germany constitutes a share of their global market and public policy in other geographic market can matter equally. Moreover, since Germany is a member of the EU and the EU has been conferred legal powers regarding environmental policy, energy policy and climate policy, EU regulation matters as well. Lastly, international multilateral policy making such as the Kyoto protocol and the international climate negotiations also have an impact on firms (cf. section 6.4.1.2).

When the objective is to induce innovation for an energy transition, it is hence not sufficient to only take a national point of view. Germany might have been less successful in inducing Energiewende relevant innovation had the German policies not been consistent with policies in other countries, the EU and the international level. What counts is a global market and hence also global politics that underscores that market development. This is also recognized by the literature. Many investigations in environmental economics consider international or EU policy one influencing factor next to domestic policies (Marth & Breitschopf, 2011; Reichardt & Rogge, 2014). Moreover the investigation of policy spillovers shows that firms are affected in their innovation activities by domestic as well as international legislation (Johnstone & Haščič, 2013; Peters et al., 2012). Peters et al. (2012) call for international demand policy schemes as a consequence.

7.3 Implications for policy makers and firms

7.3.1 Policy makers

The findings of this thesis are highly relevant for policy makers and permit to draw implications for how they can induce corporate innovation in order to pave the way for a sustainability transition such as the German Energiewende. This section develops five key lessons for policy makers, which are summarized in Table 15. In addition to elaborating the recommendation on a general level and showing how it emerged through the case studies, ideas connecting these recommendations to the current state of the Energiewende policy mix are offered.

First, the discussion on vision and strategy (cf. section 6.3.1) implies that it is pivotal that policy makers *define a vision, objectives and a roadmap for achieving these objectives for the sustainability transition*. While such vision and strategy is likely to not lead to immediate shifts in the behavior of firms it is an important input in their long-term planning process and hence induces innovation meant for the long run. The German Energiewende has such a clear vision, objectives and roadmap as defined by the 2010 Energy Concept and the post-Fukushima accelerated energy transition. Firms find it a credible and reliable indication of the long term transition expected from the German energy system.

Second, when devising strategies and policies to induce innovation it is important to *diagnose innovation problems on an actor level* in order to come up with suitable solutions for the respective innovation barriers. The case studies suggest that innovation barriers can result from a wide range of factors such as economic incentives, strategic and structural factors or cognitive biases. It is important to devise policies and policy mixes that are suitable to the innovation barriers at hand. E.g., if the barrier is that no suitable technology exists at all, the solution might be to fund basic research and R&D. If it is a lack of technological performance, implementation and commercialization, the suitable policy response is more likely to be the strengthening of market demand or the removal of systemic obstacles. Clearly this is not a new observation, also other authors have stressed the importance of the right mix of policies to address innovation problems (Rogge & Reichardt, 2013). If a policy is suitable to the innovation barrier its impact can be very powerful as the diffusion of RES-E technology after the establishment of investment security by the EEG demonstrates. A good method for identifying innovation barriers among corporate actors is to involve them in the policy process, as is done currently in the energy transition. Examples of policy-making processes that extensively involve the affected actors include the reform of the electricity market design (BMWi, 2014b), the Grid Development Plan and other electricity grid extensions (Steinbach, 2013), and, on a regional level, the climate protection process under way in North Rhine Westphalia that systematically involves corporate actors, but also the wider public (Ministerium Klimaschutz NRW, 2015). However, the difficulties with systemic regulation (cf. section 7.2.1) demonstrate that not all barriers to innovation have been fully addressed yet.

Third, the case studies have reaffirmed the role of market factors such as short and long term demand, supply and prices as critical in the context of innovation activities for a sustainability transition. Policy makers should with their policy designs hence *target the market through careful incentives and framework conditions conducive to innovation*. Demand-pull policies, especially when they involve outright financial incentives, are a powerful tool. For the market to develop an internal dynamic of innovation, market participants need to see the potential for sufficient long term returns together with a healthy degree of competition to capture these returns, the combination of which then justifies today's investment decisions. Political incentives should be set in such a way that they minimize opportunistic and short-term rent-seeking behavior. Furthermore they should be supported by a clear articulation of long term vision and strategy, measurable long-term targets to underpin the strategy and a roadmap and set of principal plans to implement this. This anchors an incentive scheme in a larger policy mix and informs and guides long-term oriented actors that may be put-off by the incentive scheme alone (cf. section 7.2.2).

Moreover, market factors are also shaped by the general framework conditions that prevail, i.e. systemic regulation. When targeting the market in an effort to induce innovation, both are equally important. The case studies have shown that inconsistencies between systemic regulation and the overall strategy have impeded innovation activities (cf. section 7.2.1). This point is especially relevant at the current state of the energy transition. Currently arguably the biggest problem of Energiewende is how to make an RES-based energy system work overall (Connect Energy Economics, 2015; Ecofys, 2016; Löschel et al., 2015). The political discourse shows that nobody has a definite answer yet. The energy system is also too complex to be centrally planned. In that situation it is important to tap into market forces to come up with solutions. However, actors need to have the incentive to develop such solutions and the freedom to experiment. Therefore systemic regulation needs to provide this e.g., through electricity market design and grid access and planning rules. The right approach for the purpose of innovation probably means that there should be little regulation and it should be simple. This is not a call for a laissez-faire energy system, but rather one for the dismantling of regulation that inadvertently belongs to and supports a fossil-nuclear energy system. For innovation it is of course important changes result in a level playing field for a wide range of actors, and not create market power. The innovative power of start-ups i.e. niche actors, as well as the transformative niches within incumbent firms needs to be maintained and harvested for the purpose of sustainable change. Unfortunately making recommendations as to what these regulatory changes entail in detail is beyond the scope to the thesis. However, contributions on this are developed by experts on the topic (Ecofys, 2016; Gerhardt et al., 2014; Grashof et al., 2015; Schulz, 2013).

Fourth, policy makers need to *think beyond national borders* in order to fully comprehend what drives the innovation activities of firms and how to induce them. The tension between the national political jurisdiction and the international orientation of firms (cf. section 7.2.3) shows that international politics need to be part of national strategy and policy. For the current state of the energy transition that means that Germany should continue its involvement on the European and international levels and push for similar strategic targets as it has set at home. Moreover, since market potential is an important motivator of innovation decisions, increasing the market size by further integrating European energy markets and also RES deployment schemes would probably benefit innovative activities.

Fifth, sometimes politicians and policy makers need to *dare to be bold* in their political and policy decisions. The stronger and faster external change occurs, the more firms are required to make internal changes. Deep and profound changes to the external environment in which firms operate forces them to explore alternative options. Such changes can be radically positive or radically negative, which probably lies in the eyes of the beholder, however, they certainly trigger action because firms have no other choice. Energiewende has several instances where bold policy decisions were taken. The accelerated Energiewende post-Fukushima constitutes such a decision with implications for the business models of incumbent electricity suppliers (cf. section 7.1.2). The EEG with its particular policy design was also bold and had far-reaching implications for change in the energy system as a whole (cf. section 7.1.1). It first created profound opportunities for new actors in the energy system, and at some point profound challenges to the incumbents through the systemic change it initiated. Systemic change brings novelties that firms have to adjust to. To initiate systemic change policies must be designed in a way that they profoundly challenge the status quo, but provide an orientation for the way forward. This thesis does not find an indication that something as radical is needed at this point of the energy transition. However, one could possibly argue that the integration of the different forms of energy (*Sektorkopplung*) needs to be pushed more forcefully in order to make the energy system overall more efficient, reliable and clean. The innovation tenders of the new EEG are a step in the right direction, but certainly not a bold one (cf. section 7.1.1). Possibly a complete ban on combustion engines as it has recently been discussed (Stockburger, 2016) would constitute such a radical political decision that will finally lead to the breakthrough of e-mobility and in turn the integration of electricity and fuels.

Table 15: Implications for policy makers

Lessons for policy makers: how to induce innovation for a sustainability transition
1. Define a vision, objectives and a roadmap for achieving these objectives for the sustainability transition
2. Diagnose innovation problems on an actor level
3. Target the market with careful incentives and framework conditions conducive to innovation
4. Think beyond national borders
5. Dare to be bold

7.3.2 Firms

This thesis also offers lessons to firms. This section presents five recommendations for how they can navigate a transition towards sustainability. They are summarized in Table 16. Most of them are geared towards incumbents more than start-ups since they struggle more with change, however, some are relevant to all.

First, for most firms innovation continues to be associated with technological research and development, the improvement of their products and possibly the improvement of their processes and operations. It is imperative that firms expand their perspective and *think in terms of systems and business models in addition to products and processes*. Throughout the case studies it has become apparent that the understanding of what innovation constitutes and how firms should look at it has already evolved significantly in the past decade or so. For electricity suppliers it is clearly the Energiewende that plays the key role here, however, digitalization is of course also important and possibly also the wider academic and management discourse where innovation has become an important topic. For example, key theoretical advancements in the management literature such as business model innovation (Chesbrough, 2007, 2010; Chesbrough & Rosenbloom, 2002) were often referred to in the interviews. Nevertheless, there remains a bias towards products and processes and technologies and R&D throughout the discussions on innovation. Of course technology and R&D are important, but firms should make an even stronger effort to explore new or alternative business models, systemic linkages of and between their products, and the possibility of market and industry fundamentals changing to such a degree that the business environment is profoundly altered.

Second, looking at the two modes of organizational learning, exploitation seems to be easier for most firms than exploration. Clearly this is the case as exploitation is more engrained in organizational routines, or, organizational routines are the result of exploitation. However, the failure of incumbent firms with established routines demonstrates that it is key to *keep exploring and nourish firm-internal niches*. In order to achieve this innovation must be a top management priority, best established if it belongs to the responsibilities of a member of the executive board. Moreover employees should be enabled to be innovative in their work and have the freedom to explore and implement ideas. Many such organizational methods to tap into the creativity and innovativeness of employees and foster intra-organizational niches have already been described in the management literature (Gupta & Singhal, 1993).

For both, innovation beyond products and processes as well as continuous exploration, certain strategic and organizational elements have proven effective. Innovation labs for example constitute physical spaces of experimentation where employees with an idea for an entrepreneurial venture are provided with the resources and support they need to realize it. They were pioneered in Silicon Valley by information technology firms such as Xerox (Chesbrough & Rosenbloom, 2002; Hiltzik & Rutkoff, 1999) and IBM (W. L. Miller, 2001). They can involve external parties such as customers, universities or political actors (Jokisch, 2007; M. Lewis & Moultrie, 2005). Other firms have been able to create such creative environments through human resource tools and processes such management support, free time for creativity, autonomy, and incentives and rewards (Alpkan, Bulut, Gunday, Ulusoy, & Kilic, 2010; Damanpour, 1991). Applications of these tools in the energy technology value chain remain limited today, although several initiatives have been started as the case study results indicate (cf. sections 6.2.3.3 and 6.2.3.5). Of course traditional elements such as investments in R&D and technological acquisitions continue to be a core element of every innovation strategy, however, these new tools can complement them and contribute towards successful corporate innovation and renewal.

Third, it has become clear that firms *rely on cooperation and open innovation to navigate uncertain environments*. Firms unanimously describe how they tap into the knowledge, competences and assets of outsiders for their activities (cf. section 6.2.3.4). Such collaboration can take a wide variety of forms such as e.g., business networks, distribution contracts, crowd sourcing, venture capital, or joint R&D projects. Often such collaborations are between start-ups and incumbents in an industry, but they might also be between firms of entirely different industries or within the same industry position. However, collaboration and open innovation do not solve all problems. Firms need to cautious to not let biases overtake the good intentions of the cooperation. For example, most firms stress that they look for complementary assets and capabilities when they determine with whom to cooperate. This is certainly a good indicator for a successful cooperation, however, the danger for incumbent firms is that by looking at complementarity and thus primarily their established competences they define partnerships too narrow and limit them to exploitation rather than engage in exploration. There is indeed empirical evidence for this elsewhere (Rothaermel, 2001). Moreover, in rather unequal partnerships between start-ups and incumbents start-ups need to be careful to not get overwhelmed and lose their new ideas within the established structure of a larger partner.

A large variety of tools now exists for leveraging the value of cooperations and open innovation. Defying traditional rules of intellectual property protection to open up source codes, develop common technology platforms, and reveal engineering knowledge in order to leverage collective intelligence and an outsider's perspective for the development of internal innovation has long been established in the information technology industry and the energy and engineering sectors are slowly warming up to it (GE Look Ahead Blog, 2015). Joint innovation and ideation with suppliers, customers or the wider public in the form of innovation platforms or topic-specific challenges is also increasingly employed (Kellner, 2015; Mascioni, 2011). Corporate venture capital is another suitable instrument for tapping into the innovative potential of external actors and has been on the rise for early and later stage investments for longer than a decade. Empirical research, however, suggests that many such vehicles do not consistently work towards strategic objectives (Ernst, Witt, & Brachtendorf, 2005) and often lack the activities and design elements that make external venture capitalists successful (S. A. Hill, Maula, Birkinshaw, & Murray, 2009).

Fourth, the case studies show that successful firms *separate very innovative activities from the rest of the organization* and hence create organizationally distinct niches within the wider organizational structure. Activities that go against the dominant logic of a firm's established operations and business model often run the risk of being discontinued (Tripsas & Gavetti, 2000). This is because they are subject to the same resource allocation processes and performance assessments of the established successful activities which, being emergent, they cannot survive. It is hence advisable to operate such disruptive units at arm's length from the rest of the organization by separating them physically and financially and developing separate performance criteria. Links between the different units, however, should be established to ensure the diffusion of knowledge and the relevance of the separate activities to the organization as a whole. Employee secondments and virtual project teams that leverage resources from throughout the organization seem to be appropriate methods.

Fifth, beyond the organizational set-up it is advisable to *stay close to politics and take an active, but open position in the policy process*. If a transition is driven by political action as is the case for Energiewende and probably most transitions towards sustainability, it makes sense to stay close to the political actors shaping the transition. Such political involvement should of course not revolve around zealous lobbying for a status quo, financial support and other corporate agendas, but ideally be a constructive exchange and resourceful advice. The energy technology value chain and incumbent electricity suppliers in particular have always been close to politics and their lobbying efforts typically come with a negative connotation (Bontrup & Marquardt, 2015; Sühlsen & Hisschemöller, 2014). It is clearly not a good idea to lobby against change that enjoys broad public support and is consistent with larger trends and landscape developments. However, done right, corporate involvement in politics can be constructive and mutually-beneficial. Firms should be constructive partners in consultations and represent their interests and expertise through individual or collective efforts. They should present themselves as discussion partners rather than rent-seekers e.g., through establishing trust by providing their expertise also without the expectation of an immediate gain.

Table 16: Implications for firms

Lessons for firms: how to navigate a systemic transition towards sustainability
1. Think in terms of systems and business models in addition to products and processes
2. Keep exploring and nourish firm-internal niches
3. Rely on cooperation and open innovation to navigate uncertain environments
4. Separate very innovative activities from the rest of the organization
5. Stay close to politics and take an active, but open position in the policy process

8 Conclusion

8.1 Summary of the thesis

The interest and guiding research question of this thesis was to explore the effect of the German energy transition on corporate innovation. To this end three steps were taken. First, Energiewende was positioned within the context of innovation (chapters 3-5), second, the effect of Energiewende on innovation was explored through a series of exploratory qualitative case studies with firms of the energy technology value chain (chapter 6), and third, implications for policy makers and firms were drawn (chapter 7). The main results are summarized here in terms of the research questions posed in the beginning of this thesis (section 1.2).

Innovation is an important secondary objective of Energiewende. Energiewende is the political course of action that drives a socio-technical transformation of the German energy system in an effort to make it greenhouse gas emissions and nuclear free. References to corporate innovation as an objective of Energiewende are made explicitly and implicitly throughout policy documents. Innovation is sought to lower the costs of the energy transition, find solutions for an RES-based energy system that do not exist yet, and secure the competitiveness of the German economy (research question I.1, chapter 3).

While an innovation effect of the energy transition is investigated through the federal government's official monitoring process as well as independent academic contributions, no consensus regarding such an effect currently exists. Diverging findings are especially due to three research gaps, first, a lack of empirical research that understands Energiewende as a complex transition process, second, a lack of empirical research that employs a broad definition of innovation, and third, a lack of empirical research on the firm level. Moreover, three controversies are salient throughout the literature, first, controversies regarding the innovation impact of the EEG, second, controversies regarding the impact of the post-Fukushima "accelerated Energiewende" on innovation, and third, controversies regarding the extent to which Energiewende has triggered changes within firms. The empirical investigation in this thesis was designed to address the research gaps, the controversies were revisited after presenting the findings of the empirical investigation (research question I.2, chapter 4).

Given the definition of Energiewende as a political course of action and the research interest to investigate the effect of this on corporate innovation, the conceptual framework for the empirical investigation draws on the multi-level perspective (MLP) in sustainability transition research, environmental economics and organization and management studies. The research is predominantly positioned in the sustainability transitions literature and adopts basic premises of the MLP such as that transition processes are co-evolutionary, the three level interaction (landscape-regime-niche) is a useful heuristic to understand transitions, and that structure and agency are both important. However, given the research interest, the empirical investigation of this thesis focuses on the activities of firms on a micro level and the effect of the Energiewende policy mix on such activities, and does not classify these firms are regime or niche actors. The conceptual framework as such was a simple representation of firms and their external environment. Firms conduct three types of innovation activities: first, exploration, development and implementation, second, adoption, and third, organizational change. The rate and direction of these innovation activities is influenced by the Energiewende policy mix, other context factors and firm characteristics (research question I.3, chapter 5).

The research interest was investigated in a series of 27 exploratory qualitative case studies with firms of the energy technology value chain i.e. firms active in energy technology and materials firms, or electricity supply and transmission. The main method for data collection were episodic elite interviews with managers of these firms, 32 such managers were interviewed. The findings show that Energiewende overall and the elements of the Energiewende policy mix influenced the innovation activities that the firm conducted over time. With respect to the direction of the activities conducted as well as the intensity, or rate, at which they were conducted a pattern of innovation dynamics emerges. From the 1970s throughout the 1990s innovation activities relevant to Energiewende were mainly focused on the exploration and development of technologies for the usage of renewable energy sources (RES) and energy-efficiency. Start-up firms were important in driving the technological development especially of RES technology. Between 2000 and 2010 the interest in all Energiewende relevant technology surged. Exploration, development and implementation as well as the adoption of RES technology, energy efficiency products and services, and non-emitting conventional generation increased. From 2005 onwards, as profound changes to the energy system from the rising share of electricity from RES became apparent, the focus of innovation activities slowly shifted towards technologies for the energy system as a whole such as smart grids, energy management and energy storage. From 2011 onwards the innovation dynamics increased following the post-Fukushima accelerated energy transition, especially when it came to the search of new business models on parts of incumbent electricity suppliers. Since 2000 technological changes were also increasingly reflected on the organizational level with changes to corporate vision and strategy, organizational structures, culture and collaboration through the energy technology value chain (research question II.1, chapter 6.2)

The Energiewende policy mix was critical for several of these change dynamics. The vision and strategy embodied in long term targets for greenhouse gas emissions, energy consumption and RES deployment, and nuclear exit decisions was an important point of reference for the future development of the German energy system that firms took into account when determining the strategy, direction and intensity of innovation activities for the longer term. Technology-push policies, especially public R&D funds, were widely used by firms. Demand-pull policies, first and foremost the market-based instrument Renewable Sources Act (EEG), created a market for RES technology and hence fostered the systemic change towards an RES-based energy system. They also advanced energy efficient products and services through mainly command-and-control mechanisms such as standards. Systemic regulation had a dual effect of enabling the implementation of new technologies, especially through the systemic provisions of the EEG, but also constraining progress in other areas as several rules and regulations are still targeted at a fossil-nuclear based energy system and hence inhibit the emergence of novelties (research question II.2, chapter 6.3).

Other external factors as well as firm characteristics have also had an impact on innovation activities, either independent or intertwined with the Energiewende policy mix. Market factors and industry dynamics such as the demand for RES were critical drivers of innovation activities. They were, however, partially the results of the Energiewende policy mix. Non-German environmental policy and landscape developments have also played a role. When it comes to firm characteristics the value chain position as well as the industry position of a firm has influenced the way firms reacted to the Energiewende policy mix: electricity suppliers were more profoundly affected by the Energiewende policy mix than energy technology firms, but overall slower to react and adjust their innovation activities. Moreover, resources, capabilities and cognition have also played a role, most noteworthy here was the cognitive bias towards central, large-scale electricity generation that impeded the take up of innovation activities for renewable energy across all types of firms (research question II.3, chapter 6.4).

The findings from the case studies helped to clarify the controversies identified at the beginning of the thesis. Regarding the innovation effect of the EEG, the case study findings suggest that the EEG clearly had a positive impact on innovation activities and it not only fostered innovation activities in RES-E technology, but also in complementary technologies and systemic solutions for an RES-based energy system. Regarding the impact of the post-Fukushima accelerated energy transition, the case studies find that Fukushima did strengthen the innovation dynamics across all firms, but did in most cases not significantly influence the direction of innovation activities. However, it did trigger business model innovation efforts on parts of incumbent electricity suppliers. Regarding the changes within incumbent firms, the findings from the case studies show that incumbent behavior is influenced by strategic, structural and organizational conditions. It furthermore shows that not only incumbent electricity suppliers, but also incumbent energy technology firms struggled to adjust their innovation activities to an RES-based energy system. Lastly, it also showed that firms are not unitary, but that struggles observable on a systemic or societal level are also mirrored within firms (research question III.1, chapter 7.1).

Throughout the case studies three tensions emerged with regards to the effect of the Energiewende policy mix on innovation. First, the progressive vision and strategy promoting an RES-based energy system are in tension with systemic regulation in the spirit of the old fossil-nuclear based energy system. Second, the allure of short term incentives might impede long term innovation activities necessary for a successful energy transition. Third, national political jurisdiction is insufficient to trigger innovation activities in firms with a global outlook and activities (research question III.1, chapter 7.2).

The findings of the case studies in general as well as the insights regarding the controversies and the identification of tensions were useful in devising recommendations for policy makers and firms when it comes to how to induce innovation for a systemic change towards sustainability and how to navigate and succeed in such change. Five implications for policy makers and firms, respectively, were drawn (research question III.1, chapter 7.3).

8.2 Limitations and avenues for further research

The conceptual framework and the qualitative exploratory research methods employed have proven useful for data collection, analysis and the derivation of results and implications. Nevertheless, just as every academic work, this dissertation has limitations regarding the empirical methods and the substantive questions that could be addressed within the scope of this thesis. These limitations point to avenues for further research that could enhance the understanding of the effect of politically-driven sustainability transitions on corporate innovation.

First, some limitations stem from the qualitative research design and methods. Given that the thesis has investigated a complex phenomenon in a particular context no claim to universal validity, applicability and relevance can be made. While insightful implications were derived from the findings of the case studies they may be limited to their specific research setting and not be generalizable to other contexts. This is due to the contextual, interpretive nature of qualitative research as well as the selection of research cases that may not be representative for their population. Moreover, despite diligent pre- and post-preparation and the effort to triangulate the information provided, interviews remain a subjective account of reality. Issues related to quality assurance in qualitative research and the downsides of interview data have been laid out in the process and methods section of this thesis (cf. sections 6.1.1 and 6.1.3.1). It would advance the general understanding of the research question if some of the findings were investigated and tested using other data sources. Since the Mannheim Innovation Panel (MIP) of the Community Innovation Survey (CIS) was recently adjusted to include data collection on environmental innovation this could provide a fruitful way forward to explore the research question.

Second, while it was a deliberate decision to explore a large range of topics, especially after the literature identified research with comprehensive understandings of innovation and Energiewende as research gaps, such an approach inadvertently limits the ability to study the emerging topics in much depth. Several interesting findings, trends and tensions of this thesis deserve further investigation. For example, collaborations were found to have increased in importance because of the energy transition. A more detailed investigation of the nature and performance of such collaborations would benefit firms for their own alliancing decisions and policy makers for their understanding of firm alliances and their desirability in the context of innovation. A combination of the perspective on niche-regime struggles taken by the multi-level perspective and the literature on strategic alliances (Rothaermel, 2001) between incumbents and new entrants could certainly advance this perspective, as has been argued before (Geels, 2011). Furthermore, firm-internal transition processes emerged as an interesting subject and have not much been studied, at least not in the multi-level perspective. Moreover, the co-evolution of digitalization and the change of the energy system is also a further interesting research topic. Lastly, each of the tensions pointed out (cf. section 7.2) deserves further investigation into root causes as well as coping strategies in the context of sustainability transitions.

Third, although Energiewende has been framed as an ongoing transition, most of the analysis of its innovation effect conducted was indeed retrospective. It may, however, still be worthwhile to focus the attention further on current dynamics and barriers to innovation in order shape the energy transition in the coming years. Clearly there remain ample of interesting research questions, research subjects and methods for investigation around the energy transition in Germany in particular and sustainability transitions as a wider field.

8.3 Overall conclusion

Innovation activities by private firms are critical to the success of the Energiewende in Germany and, moreover, transitions towards sustainability all around the globe. This thesis has shed light on how firms perceive such transitions and how the policy mix that builds such transitions towards sustainability induces innovation activities.

The Energiewende policy mix in Germany has had an overall positive effect on innovation activities as vision and strategy, the instrument mix and the systemic regulation underpinning it have set off innovation activities in firms throughout the energy technology value chain. Especially the policies targeted at market creation and the systemic change that was enforced through the rise in electricity from renewable energy sources have paved the way for firms to conduct innovation activities. Since market factors and industry dynamics have emerged as critical determinants of innovation activities in this investigation, targeting these through public policy has probably had the largest effect on innovation activities. Furthermore, the threats and opportunities presented by systemic change as such were critical in driving innovation in many areas. The conceptual framework and research design employed in this thesis have been useful to investigate the effect, and have also shown that the factors that influence innovation activities are complex and interrelated.

This thesis constitutes a contribution to the multi-level perspective in the sustainability transitions literature in the sense that it introduced actor-level studies within the

MLP and found that transitional dynamics that can be identified between actors and nodes within a system also exist within individual actors. It hence seems to be an oversimplification to attribute actors to either regimes or niches within the multi-level perspective. This insight was developed by combining the MLP with contributions from the environmental economics and organization and management literature.

In light of the risk to miss the achievement of the 2020 targets of the Energy Concept that currently haunts Energiewende, innovation is more important than ever. Policy makers should pay more attention to innovation on the corporate level as a pre-condition for making Energiewende work. They could take the recommendations developed in this thesis as a starting point. Likewise firms should continue to contribute actively towards shaping the energy transition and be careful to keep exploring and not settle too early on a specific path. It is yet very open how the future energy system will look like and all activities currently undertaken will shape it.

9 References

Abrahamson, E., & Fombrun, C. J. (1994). Macrocultures: Determinants and consequences. *Academy of Management Review*, *19*(4), 728–755.

Aghion, P., & Howitt, P. (1992). A Model of Growth through Creative Destruction. *Econometrica*, *60*(2), 323–51.

Ahmad, S. (1966). On the theory of induced invention. *The Economic Journal*, *76*(302), 344–357.

Ahuja, G., Lampert, C. M., & Tandon, V. (2008). 1 Moving Beyond Schumpeter: Management Research on the Determinants of Technological Innovation. *The Academy of Management Annals*, *2*(1), 1–98. https://doi.org/10.1080/19416520802211446

Alpkan, L., Bulut, C., Gunday, G., Ulusoy, G., & Kilic, K. (2010). Organizational support for intrapreneurship and its interaction with human capital to enhance innovative performance. *Management Decision*, *48*(5), 732–755. https://doi.org/10.1108/00251741011043902

Andersen, E. S. (2013). Schumpeter's core works revisited. In A. Pyka & E. S. Andersen (Eds.), *Long Term Economic Development* (pp. 9–31). Berlin: Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-35125-9_2

Ansari, S., & Garud, R. (2009). Inter-generational transitions in socio-technical systems: The case of mobile communications. *Research Policy*, *38*(2), 382–392. https://doi.org/10.1016/j.respol.2008.11.009

Araújo, K. (2014). The emerging field of energy transitions: Progress, challenges, and opportunities. *Energy Research & Social Science*, *1*, 112–121. https://doi.org/10.1016/j.erss.2014.03.002

Arbussa, A., & Coenders, G. (2007). Innovation activities, use of appropriation instruments and absorptive capacity: Evidence from Spanish firms. *Research Policy*, *36*(10), 1545–1558.

Arrow, K. J. (1962a). Economic welfare and the allocation of resources for invention. In NBER (Ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors* (pp. 609–626). Princeton University Press. Retrieved from http://link.springer.com/chapter/10.1007/978-1-349-15486-9_13

Arrow, K. J. (1962b). The economic implications of learning by doing. *The Review of Economic Studies*, 155–173.

Audia, P. G., & Rider, C. I. (2005). A Garage and an Idea: What More Does an Entrepreneur Need? *California Management Review*, *48*(1), 6–28. https://doi.org/10.2307/41166325

Augenstein, K. (2015). E-mobility as a sustainable system innovation: insights from a captured niche. Retrieved from http://epub.wupperinst.org/frontdoor/index/index/docId/5832

Augenstein, K., & Palzkill, A. (2015). The Dilemma of Incumbents in Sustainability Transitions: A Narrative Approach. *Administrative Sciences*, *6*(1), 1. https://doi.org/10.3390/admsci6010001

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, *17*(1), 99–120.

Barr, P. S. (1998). Adapting to unfamiliar environmental events: A look at the evolution of interpretation and its role in strategic change. *Organization Science*, *9*(6), 644–669.

Baumol, W. J. (1988). *The theory of environmental policy*. Cambridge University Press.

Baumol, W. J. (2004). Entrepreneurial enterprises, large established firms and other components of the free-market growth machine. *Small Business Economics*, *23*(1), 9–21.

BDEW. (2016). Energiedaten. Retrieved May 4, 2016, from https://www.bdew.de/internet.nsf/id/DE_Energiedaten#cat/Daten%2FGrafiken%5CEnergie%20allgemein%5CEnergiedaten%5C3.%20Stromversorgung/3-11-wirtschaftliche-entwicklung-der-stromversorger-de

BEE e.V. (2016a). *BEE-Bilanz zum EEG 2017: Deutliche Drosselung der Energiewende, leichte Verbesserungen im Detail*. Retrieved from https://www.bee-ev.de/fileadmin/Publikationen/Positionspapiere_Stellungnahmen/20160819_BEE-Kurzbewertung_EEG_2017_web.pdf

BEE e.V. (2016b). *EEG-Reform 2016 schneidet hart ins Herz der Energiewende*. Retrieved from http://www.bee-ev.de/home/presse/mitteilungen/detailansicht/eeg-reform-2016-schneidet-hart-ins-herz-der-energiewende/

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., & Rickne, A. (2008). Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, *37*(3), 407–429.

Berger, P. L., & Luckmann, T. (1966). *The Social Construction of Reality - A Treatise in the Sociology of Knowledge*. Garden City, NY: Anchor Books.

Berkers, E., & Geels, F. W. (2011). System innovation through stepwise reconfiguration: the case of technological transitions in Dutch greenhouse horticulture (1930–1980). *Technology Analysis & Strategic Management*, *23*(3), 227–247.

Binswanger, H. P. (1974). A microeconomic approach to induced innovation. *The Economic Journal*, 940–958.

BMWi. (2011). *Research for an Environmentally Sound, Reliable and Affordable Energy Supply - 6th Energy Research Programme of the Federal Government*. Berlin. Retrieved from http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/6-energieforschungsprogramm-der-bundesregierung-en,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

BMWi. (2012a). Die Energiewende in Deutschland: Mit sicherer, bezahlbarer und umweltschonender Energie ins Jahr 2050. *Schlaglichter Der Wirtschaftspolitik*, *Sonderheft*(Nachdruck September 2012).

BMWi. (2012b). Kabinett beschließt ersten Monitoring-Bericht zur Energiewende. *Schlaglichter der Wirtschaftspolitik*, (January 2013). Retrieved from http://www.bmwi.de/Dateien/BMWi/PDF/Monatsbericht/Auszuege/01-2013-aktuelles,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

BMWi. (2014a). *Datenübersicht zum ersten Fortschritts-Bericht*. Retrieved from http://www.bmwi.de/BMWi/Redaktion/Binaer/datenuebersicht-fortschrittsbericht,property=blob,bereich=bmwi2012,sprache=de,rwb=true.xls

BMWi. (2014b). *Ein Strommarkt für die Energiewende - Diskussionspaper des Bundesministeriums für Wirtschaft und Energie (Grünbuch)*. Berlin. Retrieved from https://www.bmwi.de/BMWi/Redaktion/PDF/G/gruenbuch-gesamt,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

BMWi. (2014c). *Erster Fortschritts-Bericht Energie der Zukunft*. Retrieved from http://www.bmwi.de/DE/Mediathek/publikationen,did=672424.html

BMWi. (2014d). *Gesetzeskarte für das Energieversorgungssystem - Karte zentraler Strategien, Gesetze und Verordnungen*. Retrieved from http://www.bmwi.de/DE/Themen/Energie/Energiewende/gesetzeskarte.html?gk-regelung=gkRegelungStrategien

BMWi. (2014e, Dezember). Mehr aus Energie machen - Nationaler Aktionsplan für Energieeffizienz. Retrieved from http://www.bmwi.de/BMWi/Redaktion/PDF/M-O/nationaler-aktionsplan-energieeffizienz-nape,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

BMWi. (2014f). *Zweiter Monitoring-Bericht Energie der Zukunft*. Retrieved from http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/zweiter-monitoring-bericht-energie-der-zukunft,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

BMWi. (2015a). Datenübersicht zum vierten Monitoring-Bericht. Retrieved from http://www.bmwi.de/BMWi/Redaktion/Binaer/datenuebersicht-fortschrittsbericht-2014,property=blob,bereich=bmwi2012,sprache=de,rwb=true.xls

BMWi. (2015b). *Vierter Monitoring-Bericht Energie der Zukunft*. Retrieved from http://www.bmwi.de/DE/Mediathek/publikationen,did=739122.html

BMWi. (2015c, February). Zeitreihen zur Entwicklung der Erneuerbaren Energien in Deutschland. Retrieved from http://www.erneuerbare-energien.de/EE/Navigation/DE/Service/Erneuerbare_Energien_in_Zahlen/Zeitreihen/zeitreihen.html

BMWi. (2016a). BMWi - NAPE-Meter. Retrieved September 4, 2016, from http://www.bmwi.de/DE/Themen/Energie/Energieeffizienz/NAPE/infografik-nape.html

BMWi. (2016b). Monitoring der Energiewende. Retrieved July 18, 2016, from http://www.bmwi.de/DE/Themen/Energie/Energiewende/monitoring-prozess.html

BMWi. (2016c, March 29). Gesetzeskarte für das Energieversorgungssystem - Karte zentraler Strategien, Gesetze und Verordnungen. Retrieved September 4, 2016, from http://www.bmwi.de/BMWi/Redaktion/Meldung/Gesetzeskarte/gesetzeskarte,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

Böhringer, C., Cuntz, A., Harhoff, D., & Otoo, E. A. (2014). *The Impacts of Feed-in Tariffs on Innovation: Empirical Evidence from Germany* (Working Paper No. V-363-14). University of Oldenburg, Department of Economics. Retrieved from http://ideas.repec.org/p/old/dpaper/363.html

Bointner, R. (2014). Innovation in the energy sector: Lessons learnt from R&D expenditures and patents in selected IEA countries. *Energy Policy*. https://doi.org/10.1016/j.enpol.2014.06.001

Bontrup, H.-J., & Marquardt, R.-M. (2015). *Die Zukunft der großen Energieversorger | Greenpeace-Studie*. Hannover/Lüdinghausen. Retrieved from https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/zukunft-energieversorgung-studie-20150309.pdf

Bosman, R., Loorbach, D., Frantzeskaki, N., & Pistorius, T. (2014). Discursive regime dynamics in the Dutch energy transition. *Environmental Innovation and Societal Transitions*, *13*, 45–59. https://doi.org/10.1016/j.eist.2014.07.003

Bossel, H., Krause, F., & Müller-Reissmann, K. F. (1980). Energiewende. *Wachstum Und Wohlstand Ohne Erdöl Und Uran. Ein Alternativ-Bericht Des Öko-Instituts, Frankfurt Am Main*.

Breitschopf, B. (2015). Impacts of policies on market formation and competitiveness - The case of the PV industry in Germany. *Fraunhofer ISI Working Paper Sustainability and Innovation*, *No. S 10/2015*. Retrieved from http://www.isi.fraunhofer.de/isi-wAssets/docs/e-x/working-papers-sustainability-and-innovation/WP10_2015_Impacts-of-policies_PV-industry-in-Germany.pdf

Brundtland, G., Khalid, M., Agnelli, S., Al-Athel, S., Chidzero, B., Fadika, L., … others. (1987). Our Common Future ($\backslash$'Brundtland report$\backslash$'). Retrieved from http://www.citeulike.org/group/13799/article/13602458

Buchan, D. (2012). *The Energiewende - Germany's Gamble*. Oxford Institute for Energy Studies. Retrieved from http://www.oxfordenergy.org/wpcms/wp-content/uploads/2012/07/SP-26.pdf

Buchanan, J. M., Tollison, R. D., & Tullock, G. (1980). *Toward a theory of the rent-seeking society*. Texas A & M Univ Pr.

Bulkeley, H., & Newell, P. (2015). *Governing climate change*. Routledge.

Bundesnetzagentur. (2014). *Monitoringbericht 2009*. Bonn. Retrieved from http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Energie/Unternehmen_Institutionen/DatenaustauschUndMonitoring/Monitoring/Monitoringbericht2009.pdf?__blob=publicationFile&v=2

Bundesnetzagentur. (2015). *Evaluierungsbericht nach § 33 Anreizregulierungsverordnung*. Bonn. Retrieved from http://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2015/ARegV_Evaluierungsbericht_2015.pdf?__blob=publicationFile&v=3

Bundesnetzagentur, & Bundeskartellamt. (2016). *Monitoringbericht 2015*. Bonn. Retrieved from https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Allgemeines/Bundesnetzagentur/Publikationen/Berichte/2015/Monitoringbericht_2015_BA.pdf?__blob=publicationFile&v=3

Bundesregierung. (2010, September 28). Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply. Retrieved from http://www.bmwi.de/English/Redaktion/Pdf/energy-concept,property=pdf,bereich=bmwi,sprache=en,rwb=true.pdf

Bundesregierung. (2011a, März). Atommoratorium | Energiewende beschleunigen. Retrieved August 28, 2016, from https://www.bundesregierung.de/Content/DE/StatischeSeiten/Breg/Energiekonzept/07-energiewende-beschleunigen.html

Bundesregierung. (2011b, June 9). Regierungserklärung von Bundeskanzlerin Angela Merkel zur Energiepolitik "Der Weg zur Energie der Zukunft" (Mitschrift). Retrieved September 4, 2016, from https://www.bundesregierung.de/ContentArchiv/DE/Archiv17/Regierungserklaerung/2011/2011-06-09-merkel-energie-zukunft.html

Bürer, M. J., & Wüstenhagen, R. (2009). Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors. *Energy Policy*, *37*(12), 4997–5006.

Burgelman, R. A. (1983). A process model of internal corporate venturing in the diversified major firm. *Administrative Science Quarterly*, 223–244.

Bush, V. (1945). Science: The endless frontier. *Transactions of the Kansas Academy of Science (1903-)*, *48*(3), 231–264.

Cames, M. (2010). *Emissions Trading and Innovation: A Theoretical and Empirical Analysis with a Specific Focus on the German Electricity Industry*. Saarbrücken: Suedwestdeutscher Verlag fuer Hochschulschriften.

Cantner, U., Graf, H., Herrmann, J., & Kalthaus, M. (2014). *Inventor networks in renewable energies: The influence of the policy mix in Germany* (No. 2014-034). Jena Economic Research Papers. Retrieved from http://www.econstor.eu/handle/10419/108541

Chapman, L. (2007). Transport and climate change: a review. *Journal of Transport Geography*, *15*(5), 354–367.

Chazan, G. (2016, May 18). Eon and RWE pursue radical restructurings. *Financial Times*. Retrieved from https://www.ft.com/content/316ce884-1cdc-11e6-a7bc-ee846770ec15

Chen, R. (1996). Technological expansion: The interaction between diversification strategy and organizational capability. *Journal of Management Studies*, *33*(5), 649–666.

Chesbrough, H. W. (2003). The Era of Open Innovation. *MIT Sloan Management Review*, *44*(3), 35–41.

Chesbrough, H. W. (2006). *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Press.

Chesbrough, H. W. (2007). Business model innovation: it’s not just about technology anymore. *Strategy & Leadership*, *35*(6), 12–17.

Chesbrough, H. W. (2010). Business model innovation: opportunities and barriers. *Long Range Planning*, *43*(2), 354–363.

Chesbrough, H. W., & Rosenbloom, R. S. (2002). The role of the business model in capturing value from innovation: evidence from Xerox Corporation’s technology spin-off companies. *Industrial and Corporate Change*, *11*(3), 529–555.

Christensen, C. M. (1997). *The innovator’s dilemma: when new technologies cause great firms to fail* (1st edition). Cambridge: Harvard Business Press. Retrieved from http://www.citeulike.org/group/236/article/219653

Christensen, C. M., & Bower, J. L. (1996). Customer power, strategic investment, and the failure of leading firms. *Strategic Management Journal*, *17*(3), 197–218.

Christensen, C. M., & Rosenbloom, R. S. (1995). Explaining the attacker’s advantage: Technological paradigms, organizational dynamics, and the value network. *Research Policy*, *24*(2), 233–257.

Coe, D. T., & Helpman, E. (1995). International r&d spillovers. *European Economic Review*, *39*(5), 859–887.

Cohen, W. M. (1995). Empirical Studies of Innovative Activity “, in: Stoneman, P.(ed.) Handbook of The Economics of Innovation and Technological Change. Oxford: Blackwell.

Cohen, W. M. (2010). Fifty years of empirical studies of innovative activity and performance. *Handbook of the Economics of Innovation*, *1*, 129–213.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly*, 128–152.

Connect Energy Economics. (2015). *Aktionsplan Last- Management* (Endbericht einer Studie von Connect Energy Ecomomics No. 071/07-S-2015/DE). Berlin: Studie im Auftrag von Agora Energiewende. Retrieved from https://www.agora-energiewende.de/de/themen/-agothem-/Produkt/produkt/83/Aktionsplan+Lastmanagement/

Cook, J., Nuccitelli, D., Green, S. A., Richardson, M., Winkler, B., Painting, R., … Skuce, A. (2013). Quantifying the consensus on anthropogenic global warming in the scientific literature - IOPscience. *Environmental Research Letters*, *8*(2). Retrieved from http://iopscience.iop.org/article/10.1088/1748-9326/8/2/024024;jsessionid=28EE45B32B2568EF55097A2799809D16.c2.iopscience.cld.iop.org

Correlje, A., & Van der Linde, C. (2006). Energy supply security and geopolitics: A European perspective. *Energy Policy*, *34*(5), 532–543.

Cyert, R. M., & March, J. G. (1963). A behavioral theory of the firm. *Englewood Cliffs, NJ*, *2*.

Daft, R. L., & Weick, K. E. (1984). Toward a model of organizations as interpretation systems. *Academy of Management Review*, *9*(2), 284–295.

Damanpour, F. (1991). Organizational Innovation: A Meta-Analysis Of Effects Of Determinants and Moderators. *Academy of Management Journal*, *34*(3), 555–590. https://doi.org/10.2307/256406

Danish Government. (2011, February). Energy Strategy 2050. Retrieved from http://www.efkm.dk/sites/kebmin.dk/files/news/from-coal-oil-and-gas-to-green-energy/Energy%20Strategy%202050%20web.pdf

de Haan, J. H., & Rotmans, J. (2011). Patterns in transitions: understanding complex chains of change. *Technological Forecasting and Social Change*, *78*(1), 90–102.

Dechezleprêtre, A., & Glachant, M. (2014). Does foreign environmental policy influence domestic innovation? Evidence from the wind industry. *Environmental and Resource Economics*, *58*(3), 391–413.

Del Río González, P. (2009). The empirical analysis of the determinants for environmental technological change: A research agenda. *Ecological Economics*, *68*(3), 861–878. https://doi.org/10.1016/j.ecolecon.2008.07.004

Di Stefano, G., Gambardella, A., & Verona, G. (2012). Technology push and demand pull perspectives in innovation studies: Current findings and future research directions. *Research Policy*, *41*(8), 1283–1295. https://doi.org/10.1016/j.respol.2012.03.021

Diekmann, J., & Horn, M. (2007). *Abschlussbericht Fachgespräch zur Bestandsaufnahme und methodischen Bewertung vorliegender Ansätze zur Quantifizierung der Förderung erneuerbarer Energien im Vergleich zur Förderung der Atomenergie in Deutschland im Auftrag des BMU*. Berlin: DIW. Retrieved from http://buchwald-b.de/downloads/gutachtendiwfrontal21.pdf

DiMaggio, P. J., & Powell, W. W. (1983). The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review*, *48*(2), 147–160.

Dosi, G. (1982). Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. *Research Policy*, *11*(3), 147–162.

Dosi, G. (1988). Sources, Procedures, and Microeconomic Effects of Innovation. *Journal of Economic Literature*, *26*(3), 1120–1171.

Dosi, G., & Nelson, R. R. (1994). An introduction to evolutionary theories in economics. *Journal of Evolutionary Economics*, *4*(3), 153–172. https://doi.org/10.1007/BF01236366

Dosi, G., & Nelson, R. R. (2010). Technical change and industrial dynamics as evolutionary processes. *Handbook of the Economics of Innovation*, *1*, 51–127.

Dutton, J. E., & Jackson, S. E. (1987). Categorizing strategic issues: Links to organizational action. *Academy of Management Review*, *12*(1), 76–90.

Easterlin, R. A. (1995). Will raising the incomes of all increase the happiness of all? *Journal of Economic Behavior & Organization*, *27*(1), 35–47.

Easterly, W., & Levine, R. (2002). It's not factor accumulation: stylized facts and growth models. Retrieved from http://200.10.182.196/estudios/documentos-trabajo/pdf/dtbc164.pdf

Ecofys. (2016). *Flex-Efficiency. Ein Konzept zur Integration von Effizienz und Flexibilität bei industriellen Verbrauchern.* (Studie im Auftrag von Agora Energiewende No. 093/01-S-2016/DE). Berlin: Agora Energiewende, Ecofys. Retrieved from https://www.agora-energiewende.de/de/themen/-agothem-/Produkt/produkt/286/Flex-Efficiency/

EFI, C. of E. of R. and I. (2014). *Research, innovation and technological performance in Germany – EFI Report 2014*. Berlin: EFI. Retrieved from http://www.e-fi.de/fileadmin/Gutachten_2014/EFI_Report_2014.pdf

EIA. (2016, June). Short-Term Energy Outlook. Retrieved from https://www.eia.gov/forecasts/steo/realprices/

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532–550.

Eisenhardt, K. M., & Martin, J. A. (2000). Dynamic capabilities: what are they? *Strategic Management Journal*, *21*(10–11), 1105–1121.

Emodi, N. V., Shagdarsuren, G., & Tiky, A. Y. (2015). Influencing Factors Promoting Technological Innovation in Renewable Energy. *International Journal of Energy Economics and Policy*, *5*(3), 889–900.

Energinet.dk. (2016, January 15). New record-breaking year for Danish wind power. Retrieved October 11, 2016, from http://energinet.dk/EN/El/Nyheder/Sider/Dansk-vindstroem-slaar-igen-rekord-42-procent.aspx

Engau, C., & Hoffmann, V. H. (2011). Strategizing in an Unpredictable Climate: Exploring Corporate Strategies to Cope with Regulatory Uncertainty. *Long Range Planning*, *44*(1), 42–63. https://doi.org/10.1016/j.lrp.2010.11.003

E.ON SE. (2016). Abspaltung der Uniper Gruppe - E.ON SE. Retrieved December 29, 2016, from http://www.eon.com/de/investoren/separation-from-uniper-group.html

EPIA. (2009). Global Market Outlook for Photovoltaics Until 2013.

Ernst, H., Witt, P., & Brachtendorf, G. (2005). Corporate venture capital as a strategy for external innovation: an exploratory empirical study. *R&D Management*, *35*(3), 233–242. https://doi.org/10.1111/j.1467-9310.2005.00386.x

European Commission. (2014a). *A policy framework for climate and energy in the period from 2020 to 2030* (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions No. COM/2014/015 final). Brussels: EU Directorate General Energy. Retrieved from http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:52014DC0015

European Commission. (2014b). *Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy* (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions No. SWD(2014) 255/256 final). Brussels: EU Directorate General Energy. Retrieved from https://ec.europa.eu/energy/sites/ener/files/documents/2014_eec_communication_adopted_0.pdf

Evangelista, R., Sandven, T., Sirilli, G., & Smith, K. (1998). Measuring innovation in European industry. *International Journal of the Economics of Business*, *5*(3), 311–333.

Falkner, G., Hartlapp, M., & Treib, O. (2007). Worlds of compliance: Why leading approaches to European Union implementation are only 'sometimes-true theories.' *European Journal of Political Research*, *46*(3), 395–416. https://doi.org/10.1111/j.1475-6765.2007.00703.x

Farjoun, M. (2010). Beyond dualism: Stability and change as a duality. *Academy of Management Review*, *35*(2), 202–225.

finanzen.net. (2016a, April 3). EEX Strom Phelix Baseload Year Futurepreis. Retrieved April 3, 2016, from http://www.finanzen.net/rohstoffe/eex-strom-phelix-baseload-year-future/historisch

finanzen.net. (2016b, April 3). RWE AG Aktienkurs 2006-2016. Retrieved April 3, 2016, from http://www.finanzen.net/historische-kurse/RWE

Fischedick, M., & Thomas, S. (2013). Energiewende in Deutschland, eine komplexe Transformationsaufgabe und die besondere Rolle der Energieeffizienz. In T. Kästner & H. Rentz (Eds.), *Handbuch Energiewende* (pp. 295–307). Essen: ETV. Retrieved from https://epub.wupperinst.org/frontdoor/index/index/docId/5158

Flick, U. (2014). *An Introduction to Qualitative Research* (5th edition.). Los Angeles: Sage Publications Ltd.

Freeman, C. (1994). The economics of technical change. *Cambridge Journal of Economics*, 463–514.

Frondel, M., Horbach, J., & Rennings, K. (2007). End-of-pipe or cleaner production? An empirical comparison of environmental innovation decisions across OECD countries. *Business Strategy and the Environment*, *16*(8), 571–584. https://doi.org/10.1002/bse.496

Frondel, M., Ritter, N., Schmidt, C. M., & Vance, C. (2010). Economic impacts from the promotion of renewable energy technologies: The German experience. *Energy Policy*, *38*(8), 4048–4056. https://doi.org/10.1016/j.enpol.2010.03.029

Fuchs, G., Hinderer, N., Kungl, G., & Neukirch, M. (2012). Adaptive capacities, path creation and variants of sectoral change. The Case of the Transformation of the German Energy Supply System. *SOI Discussion Paper 2012-02*. Retrieved from http://www.uni-stuttgart.de/ soz/oi/publikationen/soi_2012_2_fuchs_hinderer_kungl_neukirch_adaptive_capacities.pdf

Fürstenwerth, D., Praetorius, B., & Redl, C. (2014). *Ausschreibungen für Erneuerbare Energien - Welche Fragen sind zu prüfen?* Berlin: Agora Energiewende, Fraunhofer ISI, Consentec, TU Wien. Retrieved from https://www.agora-energiewende.de/fileadmin/downloads/publikationen/Hintergrund/Ausschreibungsmodelle/Agora_Ausschreibungen_fuer_Erneuerbare_Energien_web.pdf

Garud, R., Gehman, J., & Karnøe, P. (2010). Categorization by association: nuclear technology and emission-free electricity. In W. D. Sine & R. David (Eds.), *Research in the Sociology of Work* (pp. 51–93). Bingley, UK: Emerald Group Publishing.

Garud, R., & Karnøe, P. (2001). Path creation as a process of mindful deviation. *Path Dependence and Creation*, *138*.

Gassmann, O., Enkel, E., & Chesbrough, H. W. (2010). The future of open innovation. *R&d Management*, *40*(3), 213–221.

Gawel, E., Lehmann, P., Korte, K., Strunz, S., Bovet, J., Köck, W., … Wassermann, S. (2014). The future of the energy transition in Germany. *Energy, Sustainability and Society*, *4*(1), 1–9. https://doi.org/10.1186/s13705-014-0015-7

GE Look Ahead Blog. (2015, April 24). Putting Energy Into Open Innovation. Retrieved January 5, 2017, from http://www.gereports.com/post/117191847353/putting-energy-into-open-innovation-2/

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, *31*(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6), 897–920.

Geels, F. W. (2005). The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). *Technology Analysis & Strategic Management*, *17*(4), 445–476.

Geels, F. W. (2007). Feelings of discontent and the promise of middle range theory for STS examples from technology dynamics. *Science, Technology & Human Values*, *32*(6), 627–651.

Geels, F. W. (2010). Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy*, *39*(4), 495–510.

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions*, *1*(1), 24–40.

Geels, F. W. (2012). A socio-technical analysis of low-carbon transitions: introducing the multi-level perspective into transport studies. *Journal of Transport Geography*, *24*, 471–482.

Geels, F. W., & Kemp, R. (2007). Dynamics in socio-technical systems: Typology of change processes and contrasting case studies. *Technology in Society*, *29*(4), 441–455.

Geels, F. W., Kemp, R., Dudley, G., & Lyons, G. (2012). *Automobility in transition?: A socio-technical analysis of sustainable transport*. New York: Routledge. Retrieved from http://eprints.uwe.ac.uk/10818

Geels, F. W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., … Wassermann, S. (2016). The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). *Research Policy*, *45*(4), 896–913. https://doi.org/10.1016/j.respol.2016.01.015

Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, *36*(3), 399–417.

Gerhardt, N., Richts, C., Hochloff, P., Müller, T., Hilpert, J., Antoni, O., & Schulz, W. (2014). *Power-to-Heat zur Integration von ansonsten abgeregeltem Strom aus Erneuerbaren Energien* (Studie No. 046/09-S-2014/DE). Berlin: Agora Energiewende, Fraunhofer IWES, Stiftung Umweltenergierecht, Fraunhofer IFAM. Retrieved from https://www.agora-energiewende.de/fileadmin/Projekte/2013/power-to-heat/Agora_PtH_Anhang_WEB.pdf

Giddens, A. (1984). *The constitution of society: Outline of the theory of structuration*. Cambridge: Polity Press.

Giddens, A. (2009). The politics of climate change. *Cambridge, UK*. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1744-540X.2009.00557.x/abstract

Glaser, B., & Strauss, A. (1967). *The discovery of grounded theory: strategies for qualitative inquiry*. Chicago, IL: Aldin.

Godin, B. (2006). The Linear Model of Innovation The Historical Construction of an Analytical Framework. *Science, Technology & Human Values*, *31*(6), 639–667. https://doi.org/10.1177/0162243906291865

Google Trends. (2014, August 1). Interest over Time in Google News Headlines Search Results for "Energiewende", "Atomausstieg" and "Erneuerbare Energie." Retrieved August 1, 2014, from http://www.google.com/trends/

Grant, R. M., & Baden-Fuller, C. (1995). A knowledge-based theory of inter-firm collaboration. In *Academy of management proceedings* (Vol. 1995, pp. 17–21). Academy of Management. Retrieved from http://proceedings.aom.org/content/1995/1/17.short

Grashof, K., Lechtenböhmer, S., Zipp, A., Jachmann, H., Wille-Haussmann, B., & Reeg, M. (2015). Monopole, Liberalisierung, Energiewende : Strommarktdesign zwischen Wandel und Konstanz. Retrieved from https://epub.wupperinst.org/frontdoor/index/index/docId/6020

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. *Econometrica, Journal of the Econometric Society*, 501–522.

Griliches, Z. (1979). Issues in Assessing the Contribution of Research and Development to Productivity Growth. *The Bell Journal of Economics*, *10*(1), 92–116. https://doi.org/10.2307/3003321

Griliches, Z. (1990). *Patent statistics as economic indicators: a survey*. National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w3301

Grin, J., Rotmans, J., & Schot, J. (2010). Introduction: From Persistent Problems to System Innovations and Transitions. In J. Grin & J. Rotmans (Eds.), *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change* (1st edition). New York/London: Routledge.

Groebel, A. (2013, April). *Energy infrastructure development and financing in Germany*. Presented at the DG Competition Workshop on Review of the Environmental State Aid Guidelines, Brussels. Retrieved from http://ec.europa.eu/competition/state_aid/modernisation/groebel_en.pdf

Grossman, G. M., & Helpman, E. (1990). Trade, Innovation, and Growth. *The American Economic Review*, *80*(2), 86–91.

Grossman, G. M., & Helpman, E. (1991). Trade, knowledge spillovers, and growth. *European Economic Review*, *35*(2), 517–526.

Gupta, A. K., & Singhal, A. (1993). Managing Human Resources for Innovation and Creativity. *Research-Technology Management*, *36*(3), 41–48. https://doi.org/10.1080/08956308.1993.11670902

Haas, R., Resch, G., Panzer, C., Busch, S., Ragwitz, M., & Held, A. (2011a). Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources – Lessons from EU countries. *Energy*, *36*(4), 2186–2193. https://doi.org/10.1016/j.energy.2010.06.028

Haas, R., Resch, G., Panzer, C., Busch, S., Ragwitz, M., & Held, A. (2011b). Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources–Lessons from EU countries. *Energy*, *36*(4), 2186–2193.

Hagedoorn, J. (2002). Inter-firm R&D partnerships: an overview of major trends and patterns since 1960. *Research Policy*, *31*(4), 477–492.

Hagedoorn, J., & Duysters, G. (2002). External sources of innovative capabilities: the preferences for strategic alliances or mergers and acquisitions. *Journal of Management Studies*, *39*(2), 167–188.

Hajer, M. A. (2005). Coalitions, Practices, and Meaning in Environmental Politics: From Acid Rain to BSE. In D. Howarth & J. Torfing (Eds.), *Discourse Theory in European Politics* (pp. 297–315). Palgrave Macmillan UK. https://doi.org/10.1057/9780230523364_13

Hall, P., & Soskice, D. (2001). *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*. Oxford University Press.

Hallock, J. L., Wu, W., Hall, C. A., & Jefferson, M. (2014). Forecasting the limits to the availability and diversity of global conventional oil supply: Validation. *Energy*, *64*, 130–153.

Hauschildt, J., & Salomo, S. (2011). *Innovationsmanagement*. Vahlen.

Held, A., Ragwitz, M., & Haas, R. (2006). On the success of policy strategies for the promotion of electricity from renewable energy sources in the EU. *Energy & Environment*, *17*(6), 849–868.

Henderson, R. (1993). Underinvestment and incompetence as responses to radical innovation: Evidence from the photolithographic alignment equipment industry. *The RAND Journal of Economics*, *24*(2), 248–270.

Henderson, R., & Clark, K. B. (1990). Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, *35*(1), 9–30.

Hennicke, P., & Fischedick, M. (2007). *Erneuerbare Energien: mit Energieeffizienz zur Energiewende*. CH Beck.

Hicks, J. (1932). *The Theory of Wages*. London: Macmillan.

Hill, C. W., & Rothaermel, F. T. (2003). The performance of incumbent firms in the face of radical technological innovation. *Academy of Management Review*, *28*(2), 257–274.

Hill, S. A., Maula, M. V. J., Birkinshaw, J. M., & Murray, G. C. (2009). Transferability of the venture capital model to the corporate context: Implications for the performance of corporate venture units. *Strategic Entrepreneurship Journal*, *3*(1), 3–27. https://doi.org/10.1002/sej.54

Hillman, A. J., Keim, G. D., & Schuler, D. (2004). Corporate political activity: A review and research agenda. *Journal of Management*, *30*(6), 837–857.

Hiltzik, M. A., & Rutkoff. (1999). *Dealers of Lightning: Xerox PARC and the Dawn of the Computer Age*. HarperCollins Publishers.

Hippel, E. von. (2005). Democratizing innovation: The evolving phenomenon of user innovation. *Journal Für Betriebswirtschaft*, *55*(1), 63–78. https://doi.org/10.1007/s11301-004-0002-8

Hoegh-Guldberg, O., & Bruno, J. F. (2010). The impact of climate change on the world's marine ecosystems. *Science*, *328*(5985), 1523–1528.

Hood, C. C., & Margetts, H. Z. (2007). *The tools of government in the digital age*. Palgrave Macmillan.

Hoogma, R., Kemp, R., Schot, J., & Truffer, B. (2002). *Experimenting for sustainable transport: the approach of strategic niche management*. Taylor & Francis.

Hoppmann, J., Peters, M., Schneider, M., & Hoffmann, V. H. (2013). The two faces of market support—How deployment policies affect technological exploration and exploitation in the solar photovoltaic industry. *Research Policy*, *42*(4), 989–1003. https://doi.org/10.1016/j.respol.2013.01.002

Horbach, J. (2008). Determinants of environmental innovation—New evidence from German panel data sources. *Research Policy*, *37*(1), 163–173. https://doi.org/10.1016/j.respol.2007.08.006

Horbach, J., Rammer, C., & Rennings, K. (2012). Determinants of eco-innovations by type of environmental impact — The role of regulatory push/pull, technology push and market pull. *Ecological Economics*, *78*, 112–122. https://doi.org/10.1016/j.ecolecon.2012.04.005

Howlett, M., Ramesh, M., & Perl, A. (2009). *Studying Public Policy: Policy Cycles and Policy Subsystems* (3rd ed.). Oxford University Press.

Hughes, T. P. (1987). The evolution of large technological systems. In W. E. Bijker, T. P. Hughes, & T. J. Pinch, *The social construction of technological systems: New directions in the sociology and history of technology* (pp. 51–82). Cambridge: The MIT Press.

Ide, A. M. (in press). *Grenzüberschreitende Förderung Erneuerbarer Energien im europäischen Strombinnenmarkt*. Baden-Baden: Nomos.

IEA PVPS. (2012). China National Photovoltaics Status Report 2011.

IPCC. (2014). *Fifth Assessment Report - Mitigation of Climate Change*. Geneva. Retrieved from https://www.ipcc.ch/report/ar5/wg3/

IRENA. (2015). Renewable Energy Capacity Statistics 2015. Retrieved from http://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Capacity_Statistics_2015.pdf

Jacobsson, S., & Lauber, V. (2006). The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. *Energy Policy*, *34*(3), 256–276. https://doi.org/10.1016/j.enpol.2004.08.029

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2003). Chapter 11 Technological change and the environment. In Karl-Göran Mäler and Jeffrey R. Vincent (Ed.), *Handbook of Environmental Economics* (Vol. Volume 1, pp. 461–516). Elsevier. Retrieved from http://www.sciencedirect.com/science/article/pii/S1574009903010167

Jaffe, A. B., Newell, R. G., & Stavins, R. N. (2005). A tale of two market failures: Technology and environmental policy. *Ecological Economics*, *54*(2–3), 164–174. https://doi.org/10.1016/j.ecolecon.2004.12.027

Jaffe, A. B., & Stavins, R. N. (1995). Dynamic incentives of environmental regulations: The effects of alternative policy instruments on technology diffusion. *Journal of Environmental Economics and Management*, *29*(3), S43–S63.

Jahoda, M. (1989). Why a Non-reductionistic Social Psychology is Almost Too Difficult to be Tackled but Too Fascinating to be Left Alone. *British Journal of Social Psychology*, *28*, 71–78.

Jamasb, T., & Pollitt, M. (2005a). Electricity Market Reform in the European Union: Review of Progress toward Liberalization & Integration. *The Energy Journal*, *26*, 11–41.

Jamasb, T., & Pollitt, M. (2005b). Electricity market reform in the European Union: review of progress toward liberalization & integration. *The Energy Journal*, *26*, 11–41.

Jamasb, T., & Pollitt, M. (2008). Liberalisation and R&D in network industries: The case of the electricity industry. *Research Policy*, *37*(6), 995–1008.

Jamasb, T., & Pollitt, M. G. (2011). Electricity sector liberalisation and innovation: An analysis of the UK's patenting activities. *Research Policy*, *40*(2), 309–324. https://doi.org/10.1016/j.respol.2010.10.010

Jenner, S., Groba, F., & Indvik, J. (2013). Assessing the strength and effectiveness of renewable electricity feed-in tariffs in European Union countries. *Energy Policy*, *52*, 385–401. https://doi.org/10.1016/j.enpol.2012.09.046

Jensen, M. C. (2001). Value Maximization, Stakeholder Theory, and the Corporate Objective Function. *Journal of Applied Corporate Finance*, *14*(3), 8–21. https://doi.org/10.1111/j.1745-6622.2001.tb00434.x

Johnstone, N., & Haščič, I. (2013). Policy Incentives for Energy and Environmental Technological Innovation: Lessons from the Empirical Evidence. In J. F. Shogren (Ed.), *Encyclopedia of Energy, Natural Resource, and Environmental Economics* (pp. 98–106). Waltham: Elsevier. Retrieved from http://www.sciencedirect.com/science/article/pii/B9780123750679000619

Johnstone, N., Haščič, I., & Kalamova, M. (2011). Environmental Policy Design Characteristics and Innovation. In *OECD Studies on Environmental Innovation* (pp. 19–46). Organisation for Economic Co-operation and Development. Retrieved from http://www.oecd-ilibrary.org/content/chapter/9789264115620-3-en

Johnstone, N., Haščič, I., & Popp, D. (2010). Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts. *Environmental and Resource Economics*, *45*(1), 133–155. https://doi.org/10.1007/s10640-009-9309-1

Jokisch, M. (2007). *Active Integration of Users Into the Innovation Process of a Manufacturer: The BMW Customer Innovation Lab*. Hut.

Kaldor, N. (1961). *Capital accumulation and economic growth*. Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-1-349-08452-4_10

Kamien, M. I., & Schwartz, N. L. (1968). Optimal" induced" technical change. *Econometrica: Journal of the Econometric Society*, *36*(1), 1–17.

Kaplan, S., & Tripsas, M. (2008). Thinking about technology: Applying a cognitive lens to technical change. *Research Policy*, *37*(5), 790–805.

Kellner, T. (2015, February 2). Could Crowdsourcing Lead to Lower Emissions, Water Use in Shale Oil and Gas Wells? Retrieved January 5, 2017, from http://www.gereports.com/post/109489694865/could-crowdsourcing-lead-to-lower-emissions-water/

Kemp, R., & Pearson, P. (2007). *Final report MEI project about measuring eco-innovation*. Maastricht: UM-MERIT. Retrieved from http://www.oecd.org/environment/consumption-innovation/44053491.pdf

Kemp, R., & Pontoglio, S. (2011). The innovation effects of environmental policy instruments — A typical case of the blind men and the elephant? *Ecological Economics*, *72*, 28–36. https://doi.org/10.1016/j.ecolecon.2011.09.014

Kemp, R., Rip, A., & Schot, J. (2001). Constructing transition paths through the managemetn of niches. In R. Garud & P. Karnøe (Eds.), *Path Dependence and Creation*. Mahwah, New Jersey: Lawrence Erlbaum.

Kemp, R., Schot, J., & Hoogma, R. (1998). Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis & Strategic Management*, *10*(2), 175–198.

Kern, F. (2012). Using the multi-level perspective on socio-technical transitions to assess innovation policy. *Technological Forecasting and Social Change*, *79*(2), 298–310.

Kern, F., & Howlett, M. (2009). Implementing transition management as policy reforms: a case study of the Dutch energy sector. *Policy Sciences*, *42*(4), 391–408.

Kern, F., & Smith, A. (2008). Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy Policy*, *36*(11), 4093–4103.

Ketata, I., Sofka, W., & Grimpe, C. (2015). The role of internal capabilities and firms' environment for sustainable innovation: evidence for Germany. *R&D Management*, *45*(1), 60–75.

Kharas, H. (2010). The emerging middle class in developing countries. Retrieved from http://www.oecd-ilibrary.org/development/the-emerging-middle-class-in-developing-countries_5kmmp8lncrns-en

Kitzing, L., Mitchell, C., & Morthorst, P. E. (2012). Renewable energy policies in Europe: Converging or diverging? *Energy Policy*, *51*, 192–201. https://doi.org/10.1016/j.enpol.2012.08.064

Klessmann, C., Held, A., Rathmann, M., & Ragwitz, M. (2011). Status and perspectives of renewable energy policy and deployment in the European Union—What is needed to reach the 2020 targets? *Energy Policy*, *39*(12), 7637–7657.

Kline, S. J., & Rosenberg, N. (1986). An overview of innovation. In N. Rosenberg & R. Landau, *The positive sum strategy: Harnessing technology for economic growth* (p. 640). National Academies Press.

Kogut, B., & Zander, U. (1996). What firms do? Coordination, identity, and learning. *Organization Science*, *7*(5), 502–518.

Kohler, B. (2011, July 1). Kommentar zum Atomausstieg Das Ende des dreißigjährigen Krieges. *Frankfurter Allgemeine Zeitung*. Retrieved from http://www.faz.net/aktuell/politik/kommentar-zum-atomausstieg-das-ende-des-dreissigjaehrigen-krieges-17272.html

Krewitt, W. (2007). Die externen Kosten der Stromerzeugung aus erneuerbaren Energien im Vergleich zur fossilen Stromerzeugung. *Umweltwissenschaften und Schadstoff-Forschung*, *19*(3), 144–151. https://doi.org/10.1065/uwsf2007.06.193

Krueger, A. O. (1974). The political economy of the rent-seeking society. *The American Economic Review*, *64*(3), 291–303.

Kungl, G. (2015). Stewards or sticklers for change? Incumbent energy providers and the politics of the German energy transition. *Energy Research & Social Science*, *8*, 13–23.

Laird, F. N., & Stefes, C. (2009). The diverging paths of German and United States policies for renewable energy: Sources of difference. *Energy Policy*, *37*(7), 2619–2629. https://doi.org/10.1016/j.enpol.2009.02.027

Laleman, R., & Albrecht, J. (2014). Comparing push and pull measures for PV and wind in Europe. *Renewable Energy*, *61*, 33–37. https://doi.org/10.1016/j.renene.2012.04.025

Lamnek, S. (2006). *Qualitative Sozialforschung*. Weinheim: Beltz. Retrieved from https://eldorado.tu-dortmund.de/handle/2003/22166

Lauber, V., & Mez, L. (2004). Three decades of renewable electricity policies in Germany. *Energy & Environment*, *15*(4), 599–623.

Lavie, D., Stettner, U., & Tushman, M. L. (2010). Exploration and exploitation within and across organizations. *The Academy of Management Annals*, *4*(1), 109–155.

Leonard-Barton, D. (1992). Core capabilities and core rigidities: A paradox in managing new product development. *Strategic Management Journal*, *13*(S1), 111–125. https://doi.org/10.1002/smj.4250131009

Lewis, J. I., & Wiser, R. H. (2007). Fostering a renewable energy technology industry: An international comparison of wind industry policy support mechanisms. *Energy Policy*, *35*(3), 1844–1857. https://doi.org/10.1016/j.enpol.2006.06.005

Lewis, M., & Moultrie, J. (2005). The Organizational Innovation Laboratory. *Creativity and Innovation Management*, *14*(1), 73–83. https://doi.org/10.1111/j.1467-8691.2005.00327.x

Lipp, J. (2007). Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy Policy*, *35*(11), 5481–5495.

Littig, B. (2008). Interviews mit Eliten–Interviews mit ExpertInnen: Gibt es Unterschiede. In *Forum Qualitative Sozialforschung* (Vol. 9, p. 37). Retrieved from https://www.ihs.ac.at/publications/soc/misc/InterviewsEliten.pdf

Liverman, D. (2007). From Uncertain to Unequivocal. *Environment: Science and Policy for Sustainable Development*, *49*(8), 28–32. https://doi.org/10.3200/ENVT.49.8.28-32

Lockwood, M. (2016). Creating protective space for innovation in electricity distribution networks in Great Britain: The politics of institutional change. *Environmental Innovation and Societal Transitions*, *18*, 111–127. https://doi.org/10.1016/j.eist.2015.05.007

Loorbach, D. (2010). Transition management for sustainable development: a prescriptive, complexity-based governance framework. *Governance*, *23*(1), 161–183.

Löschel, A., Erdmann, G., Staiß, F., & Ziesing, H.-J. (2012). *Stellungnahme zum ersten Monitoring-Bericht der Bundesregierung für das Berichtsjahr 2011* (Expertenkommission zum Monitoring-Prozess “Energie der Zukunft”). Berlin, Mannheim, Stuttgart. Retrieved from http://www.bmwi.de/BMWi/Redaktion/PDF/M-O/monotoringbericht-stellungnahme-lang,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

Löschel, A., Erdmann, G., Staiß, F., & Ziesing, H.-J. (2014a). *Statement on the second monitoring report by the German government for 2012* (Expert commission on the “Energy of the future” monitoring process). Berlin, Mannheim, Stuttgart. Retrieved from http://www.bmwi.de/English/Redaktion/Pdf/statement-on-the-second-monitoring-report-by-the-german-government-for-2012,property=pdf,bereich=bmwi2012,sprache=en,rwb=true.pdf

Löschel, A., Erdmann, G., Staiß, F., & Ziesing, H.-J. (2014b). *Stellungnahme zum ersten Fortschrittsbericht der Bundesregierung für das Jahr 2013* (Expertenkommission zum Monitoring-Prozess “Energie der Zukunft”). Berlin, Münster, Stuttgart. Retrieved from http://www.bmwi.de/BMWi/Redaktion/PDF/M-O/monitoringbericht-energie-der-zukunft-stellungnahme-2013,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

Löschel, A., Erdmann, G., Staiß, F., & Ziesing, H.-J. (2014c). *Stellungnahme zum zweiten Monitoring-Bericht der Bundesregierung für das Berichtsjahr 2012*

(Expertenkommission zum Monitoring-Prozess “Energie der Zukunft”). Berlin, Mannheim, Stuttgart. Retrieved from http://ftp.zew.de/pub/zew-docs/gutachten/Stellungnahme_Expertenkommission_2014.pdf

Löschel, A., Erdmann, G., Staiß, F., & Ziesing, H.-J. (2015). *Stellungnahme zum vierten Monitoring-Bericht der Bundesregierung für das Berichtsjahr 2014* (Expertenkommission zum Monitoring-Prozess “Energie der Zukunft”). Berlin, Münster, Stuttgart. Retrieved from http://www.bmwi.de/BMWi/Redaktion/PDF/M-O/monitoringbericht-energie-der-zukunft-stellungnahme-2014,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf

Lucas, R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics*, *22*(1), 3–42.

Luhmann, H.-J., Fischedick, M., & Schindele, S. (2014). *Stellungnahme zur BMWi-Konsultation “Eckpunkte für ein Ausschreibungsdesign für Photovoltaik-Freiflächenanlagen” : Agrophotovoltaik (APV) als ressourceneffiziente Landnutzung*. Wuppertal: Wuppertal Inst. für Klima, Umwelt, Energie; Fraunhofer ISE. Retrieved from https://epub.wupperinst.org/frontdoor/index/index/docId/5547

Makowski, L., Wu, Q., Yagi, M., & Kokubu, K. (2015). *Does corporate environmental performance change through environmental policies between pre and post 2011? Evidence from firm-level data in Germany and Japan*. Retrieved from https://www.b.kobe-u.ac.jp/paper/2015_24.pdf

Malerba, F. (2002). Sectoral systems of innovation and production. *Research Policy*, *31*(2), 247–264.

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization Science*, *2*(1), 71–87.

March, J. G., & Simon, H. A. (1958). *Organizations*. Retrieved from http://psycnet.apa.org/psycinfo/1958-15040-000

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, *41*(6), 955–967.

Marth, H., & Breitschopf, B. (2011). Auswirkung von Politikmaßnahmen auf das Innovationsgeschehen im Bereich der Mikro-Kraft-Wärme-Kopplung. *Fraunhofer ISI Working Paper Sustainability and Innovation*, *No. S 8/2011*. Retrieved from http://www.isi.fraunhofer.de/isi-wAssets/docs/e-x/working-papers-sustainability-and-innovation/WP8-2011_mikro-kwk.pdf

Martin, R., Muûls, M., & Wagner, U. (2011). Climate change, investment and carbon markets and prices–evidence from manager interviews. *Climate Strategies, Carbon Pricing for Low-Carbon Investment Project*. Retrieved from http://climatepolicyinitiative.org/europe/files/2011/01/Climate-Change-Investment-and-Carbon-Markets-and-Prices1.pdf

Mascioni, M. (2011, February 7). Open Innovation at GE. Retrieved January 5, 2017, from https://www.technologyreview.com/s/422626/open-innovation-at-ge/

Maubach, K.-D. (2014). *Energiewende - Wege zu einer bezahlbaren Energieversorgung* (2nd ed.). Wiesbaden: Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-3-658-05474-8_3

Mayring, P. (2000). *Qualitative Inhaltsanalyse* (7. Aufl.). Weinheim: Beltz.

Mayring, P. (2012). *Qualitative Inhaltsanalyse - ein Beispiel für Mixed Methods*. (M. Gläser-Zikuda, T. Seidel, C. Rohlfs, A. Gröschner, & S. Ziegelbauer, Eds.). Münster: Waxmann Verlag.

McCarty, J. P. (2001). Ecological consequences of recent climate change. *Conservation Biology*, *15*(2), 320–331.

Meadows, D. H., Meadows, D. L., Randers, J., & Behrens, W. W. (1972). The limits to growth. *New York*, *102*.

Mebratu, D. (1998). Sustainability and sustainable development: historical and conceptual review. *Environmental Impact Assessment Review*, *18*(6), 493–520.

Merton, R. K. (1968). *Social Theory and Social Structure*. Simon and Schuster.

Miles, D. (1999). Modelling the impact of demographic change upon the economy. *The Economic Journal*, *109*(452), 1–36.

Miller, D. J., Fern, M. J., & Cardinal, L. B. (2007). The use of knowledge for technological innovation within diversified firms. *Academy of Management Journal*, *50*(2), 307–325.

Miller, W. L. (2001). Innovation for Business Growth. *Research-Technology Management*, *44*(5), 26–41. https://doi.org/10.1080/08956308.2001.11671451

Ministerium Klimaschutz NRW. (2015). *Klimaschutzplan Nordrhein-Westfalen: Klimaschutz und Klimafolgenanpassung*. Düsseldorf: Ministerium for Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen. Retrieved from https://www.klimaschutz.nrw.de/fileadmin/Dateien/Download-Dokumente/Sonstiges/NRW_BR_Klimabericht_web_januar.pdf

Mitchell, C., Bauknecht, D., & Connor, P. M. (2006). Effectiveness through risk reduction: a comparison of the renewable obligation in England and Wales and the feed-in system in Germany. *Energy Policy*, *34*(3), 297–305. https://doi.org/10.1016/j.enpol.2004.08.004

Mowery, D., & Rosenberg, N. (1979). The influence of market demand upon innovation: a critical review of some recent empirical studies. *Research Policy*, *8*(2), 102–153.

Muench, S., Thuss, S., & Guenther, E. (2014). What hampers energy system transformations? The case of smart grids. *Energy Policy*, *73*, 80–92. https://doi.org/10.1016/j.enpol.2014.05.051

Murphy, K. M., Shleifer, A., & Vishny, R. W. (1993). Why is rent-seeking so costly to growth? *The American Economic Review*, *83*(2), 409–414.

Myers, S., & Marquis, D. G. (1969). Successful industrial innovations. A study of factors underlying innovation in selected firms.

Naisbit, J. (1982). *Megatrends*. New York: Warner Books.

Nelson, R. R. (1971). The Simple Economics of Basic Scientific Research. *J. Reprints Antitrust L. & Econ.*, *3*, 725.

Nelson, R. R. (Ed.). (1993). *National innovation systems: a comparative analysis*. Oxford University Press.

Nelson, R. R., & Winter, S. G. (1974). Neoclassical vs. Evolutionary Theories of Economic Growth: Critique and Prospectus. *The Economic Journal*, *84*(336), 886–905. https://doi.org/10.2307/2230572

Nelson, R. R., & Winter, S. G. (1982). *An evolutionary theory of economic change*. Harvard University Press.

Nemet, G. F. (2009). Demand-pull, technology-push, and government-led incentives for non-incremental technical change. *Research Policy*, *38*(5), 700–709. https://doi.org/10.1016/j.respol.2009.01.004

Nesta, L., Vona, F., & Nicolli, F. (2014). Environmental policies, competition and innovation in renewable energy. *Journal of Environmental Economics and Management*, *67*(3), 396–411. https://doi.org/10.1016/j.jeem.2014.01.001

Newell, R. G., Jaffe, A. B., & Stavins, R. N. (1998). *The induced innovation hypothesis and energy-saving technological change*. National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w6437

Newell, R. G., Jaffe, A. B., & Stavins, R. N. (2006). The effects of economic and policy incentives on carbon mitigation technologies. *Energy Economics*, *28*(5–6), 563–578. https://doi.org/10.1016/j.eneco.2006.07.004

Nooteboom, B. (2005). A cognitive theory of the firm. *European Journal of Economic and Social Systems*, *18*(1), 29–60.

North, D. C. (1990). *Institutions, institutional change and economic performance*. Cambridge University Press.

Nuttall, W. J. (2004). *Nuclear renaissance: technologies and policies for the future of nuclear power*. CRC Press.

OECD, & Eurostat. (2005). *Oslo Manual - Guidelines for Collecting and Interpreting Innovation Data* (Third edition). Paris: OECD Publishing. Retrieved from https://www.destatis.de/Europa/DE/Publikationen/Eurostat/WissenschaftTechnolgoie/MW_ISBN9264013083.html

OECD/IEA. (2015). *Key World Energy Statistics 2015*. Paris. Retrieved from https://www.iea.org/publications/freepublications/publication/key-world-energy-statistics-2015.html

O'Reilly, C. A., & Tushman, M. L. (2008). Ambidexterity as a dynamic capability: Resolving the innovator's dilemma. *Research in Organizational Behavior*, *28*, 185–206.

O'Reilly, C. A., & Tushman, M. L. (2013). Organizational ambidexterity: Past, present, and future. *The Academy of Management Perspectives*, *27*(4), 324–338.

Oreskes, N. (2004). The scientific consensus on climate change. *Science*, *306*(5702), 1686–1686.

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd edition). Thousand Oaks, CA: Sage Publications Ltd.

Pegels, A., & Lütkenhorst, W. (2014). Is Germany′ s energy transition a case of successful green industrial policy? Contrasting wind and solar PV. *Energy Policy*, *74*, 522–534.

Peters, M., Schneider, M., Griesshaber, T., & Hoffmann, V. H. (2012). The impact of technology-push and demand-pull policies on technical change–Does the locus of policies matter? *Research Policy*, *41*(8), 1296–1308.

Porter, M. E. (1990). The Competitive Advantage of Nations. Retrieved from http://www.hbs.edu/faculty/Pages/item.aspx?num=189

Porter, M. E., & Stern, S. (2001). Innovation: location matters. *MIT Sloan Management Review*, *42*(4), 28.

Powell, W. W., Koput, K. W., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly*, 116–145.

Prahalad, C. K., & Bettis, R. A. (1986). The dominant logic: A new linkage between diversity and performance. *Strategic Management Journal*, *7*(6), 485–501.

Prahalad, C. K., & Hamel, G. (1990). The core competence of the corporation. *Harvard Business Review*.

Quiggin, J. (2006). Blogs, wikis and creative innovation. *International Journal of Cultural Studies*, *9*(4), 481–496. https://doi.org/10.1177/1367877906069897

Ragwitz, M., Huber, C., & Resch, G. (2007). Promotion of renewable energy sources: effects on innovation. *International Journal of Public Policy*, *2*(1), 32–56.

Ragwitz, M., Walz, R., Hoffmann, V. H., Neuhoff, K., Cantner, U., Graf, H., … Rogge, K. S. (2014). Expertenstatement Wirkung des EEG – was ist die empirische Evidenz? Retrieved from http://www.isi.fraunhofer.de/isi-de/service/presseinfos/2014/pri-04-2014-EFI-Expertenstatement.php

Rammer, C., Aschhoff, B., Crass, D., Doherr, T., Hud, M., Köhler, C., … Schwiebacher, F. (2014). *Innovationsverhalten der deutschen Wirtschaft - Indikatorenbericht zur Innovationserhebung 2013*. Mannheim: Zentrum für Europäische Wirtschaftsforschung (ZEW). Retrieved from ftp://ftp.zew.de/pub/zew-docs/mip/13/mip_2013.pdf

Rammer, C., Crass, D., Doherr, T., Hud, M., Hünermund, P., Iferd, Y., … Schubert, T. (2016). *Innovationsverhalten der deutschen Wirtschaft - Indikatorenbericht zur Innovationserhebung 2015*. Mannheim: Zentrum für Europäische Wirtschaftsforschung (ZEW). Retrieved from http://www.zew.de/fileadmin/FTP/mip/15/mip_2015.pdf

Raven, R., & Verbong, G. (2007). Multi-regime interactions in the Dutch energy sector: The case of combined heat and power technologies in the Netherlands 1970–2000. *Technology Analysis & Strategic Management*, *19*(4), 491–507.

Reichardt, K., & Rogge, K. S. (2014). How the policy mix and its consistency impact innovation: findings from company case studies on offshore wind in Germany. *Fraunhofer ISI Working Paper Sustainability and Innovation*, *No. S 7/2014*. Retrieved from http://www.isi.fraunhofer.de/isi-wAssets/docs/e-x/working-papers-sustainability-and-innovation/WP07-2014_PolicyMix-and-its-consistency-impact.pdf

Reichardt, K., Rogge, K. S., & Negro, S. (2015). Unpacking the policy processes for addressing systemic problems: The case of the technological innovation system of offshore wind in Germany. *Fraunhofer ISI Working Paper Sustainability and Innovation*, *No. S 02/2015*. Retrieved from http://www.isi.fraunhofer.de/isi-wAssets/docs/e-x/working-papers-sustainability-and-innovation/WP02-2015_Unpacking-policy-processes.pdf

Rennings, K. (2000). Redefining innovation — eco-innovation research and the contribution from ecological economics. *Ecological Economics*, *32*(2), 319–332. https://doi.org/10.1016/S0921-8009(99)00112-3

Rennings, K., & Rammer, C. (2009). Increasing energy and resource efficiency through innovation-an explorative analysis using innovation survey data. *ZEW-Centre for European Economic Research Discussion Paper*, (2009/56).

Rennings, K., & Rexhäuser, S. (2014). Innovationswirkungen der Energiewende. *GAIA - Ecological Perspectives for Science and Society*, *23*(4), 356–357.

Requate, T. (2005). Dynamic incentives by environmental policy instruments—a survey. *Ecological Economics*, *54*(2–3), 175–195. https://doi.org/10.1016/j.ecolecon.2004.12.028

Reuveny, R. (2007). Climate change-induced migration and violent conflict. *Political Geography*, *26*(6), 656–673.

Rexhäuser, S., & Löschel, A. (2014). Invention in Energy Technologies: Comparing Energy Efficiency and Renewable Energy Inventions at the Firm Level. *ZEW Discussion Papers*, *No. 14-036*. Retrieved from http://ftp.zew.de/pub/zew-docs/dp/dp14036.pdf

Richards, D. (1996). Elite interviewing: Approaches and pitfalls. *Politics*, *16*(3), 199–204.

Richter, M. (2013a). Business model innovation for sustainable energy: German utilities and renewable energy. *Energy Policy*, *62*, 1226–1237.

Richter, M. (2013b). German utilities and distributed PV: How to overcome barriers to business model innovation. *Renewable Energy*, *55*, 456–466. https://doi.org/10.1016/j.renene.2012.12.052

Rip, A., & Kemp, R. (1998). *Technological change*. Battelle Press.

Rodrik, D., Subramanian, A., & Trebbi, F. (2004). Institutions rule: the primacy of institutions over geography and integration in economic development. *Journal of Economic Growth*, *9*(2), 131–165.

Rogers, E. (1962). *Diffusion of innovations* (1st ed.). New York: Free Press.

Rogge, K. S., & Hoffmann, V. H. (2010). The impact of the EU ETS on the sectoral innovation system for power generation technologies – Findings for Germany. *Energy Policy*, *38*(12), 7639–7652. https://doi.org/10.1016/j.enpol.2010.07.047

Rogge, K. S., & Reichardt, K. (2013). Towards a more comprehensive policy mix conceptualization for environmental technological change: a literature synthesis. *Fraunhofer ISI Working Paper Sustainability and Innovation*, *No. S 3/2013*. Retrieved from http://www.isi.fraunhofer.de/isi-wAssets/docs/e-x/de/working-papers-sustainability-and-innovation/WP03_13_acknupdate_-policy-mix-concept.pdf

Rogge, K. S., Schleich, J., Haussmann, P., Roser, A., & Reitze, F. (2011). The role of the regulatory framework for innovation activities: The EU ETS and the German paper industry. *Fraunhofer ISI Working Paper Sustainability and Innovation*, *No. S 1/2011*. Retrieved from http://www.isi.fraunhofer.de/isi-wAssets/docs/e-x/working-papers-sustainability-and-innovation/WP1-2011_EU-ETS_German-Paper-Industry.pdf

Rogge, K. S., Schneider, M., & Hoffmann, V. H. (2011). The innovation impact of the EU Emission Trading System — Findings of company case studies in the German power sector. *Ecological Economics*, *70*(3), 513–523. https://doi.org/10.1016/j.ecolecon.2010.09.032

Römer, B., Reichhart, P., Kranz, J., & Picot, A. (2012). The role of smart metering and decentralized electricity storage for smart grids: The importance of positive externalities. *Energy Policy*, *50*, 486–495. https://doi.org/10.1016/j.enpol.2012.07.047

Romer, P. M. (1986). Increasing Returns and Long-Run Growth. *The Journal of Political Economy*, *94*(5), 1002–1037.

Romer, P. M. (1987). Growth based on increasing returns due to specialization. *The American Economic Review*, *77*(2), 56–62.

Romer, P. M. (1990). Endogenous Technological Change. *Journal of Political Economy*, *98*(5), S71-102.

Romer, P. M. (1994). The origins of endogenous growth. *The Journal of Economic Perspectives*, 3–22.

Roques, F. A. (2008). Market Design for Generation Adequacy: Healing Causes rather than Symptoms. *Utilities Policy*, *16*(3), 171–183.

Roques, F. A., Newbery, D. M., & Nuttall, W. J. (2005). Investment incentives and electricity market design: the British experience. *Review of Network Economics*, *4*(2).

Rosenberg, M. J. (2001). *E-learning: Strategies for delivering knowledge in the digital age* (Vol. 3). McGraw-Hill New York. Retrieved from http://www.ifets.info/journals/6_3/11.html

Rothaermel, F. T. (2001). Complementary assets, strategic alliances, and the incumbent's advantage: an empirical study of industry and firm effects in the biopharmaceutical industry. *Research Policy*, *30*(8), 1235–1251.

Rumelt, R. P., & Lamb, R. (1997). Towards a strategic theory of the firm. In *Resources, firms, and strategies: A reader in the resource-based perspective* (pp. 131–145).

RWE AG. (2016, January 13). RWE will weiter bei den Erneuerbaren wachsen. Retrieved January 29, 2017, from http://www.rwe.com/web/cms/de/37110/rwe/presse-news/pressemitteilungen/pressemitteilungen/?pmid=4014457

Schaltegger, S., Lüdeke-Freund, F., & Hansen, E. G. (2012). Business cases for sustainability: the role of business model innovation for corporate sustainability. *International Journal of Innovation and Sustainable Development*, *6*(2), 95–119. https://doi.org/10.1504/IJISD.2012.046944

Schmidt, T., & Rammer, C. (2007). Non-technological and technological innovation: strange bedfellows? *ZEW-Centre for European Economic Research Discussion Paper*, (7–52). Retrieved from http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1010301

Schmidt, T. S., Schneider, M., Rogge, K. S., Schuetz, M. J. A., & Hoffmann, V. H. (2012). The effects of climate policy on the rate and direction of innovation: A survey of the

EU ETS and the electricity sector. *Environmental Innovation and Societal Transitions*, *2*, 23–48. https://doi.org/10.1016/j.eist.2011.12.002

Schmiedeberg, C. (2008). Complementarities of innovation activities: An empirical analysis of the German manufacturing sector. *Research Policy*, *37*(9), 1492–1503. https://doi.org/10.1016/j.respol.2008.07.008

Schmookler, J. (1962). Economic sources of inventive activity. *The Journal of Economic History*, *22*(01), 1–20.

Schmookler, J. (1966). *Invention and Economic Growth*. Boston: Harvard University Press. Retrieved from http://philpapers.org/rec/SCHIAE-10

Schulz, T. (2013, May). *Stabilität durch flexibilität: Demand Response und Virtuelle Kraftwerke als Schlüssel zum neuen Energiesystem*. Berlin. Retrieved from http://www.agora-energiewende.org/fileadmin/downloads/externe_Praesentationen/03_Schulz_Stabilitaet_durch_Flexibilitaet.pdf

Schumpeter, J. A. (1942). *Capitalism, socialism and democracy* (Reprinted 2008). New York: HarperCollins.

Schumpeter, J. A. (1947). The Creative Response in Economic History. *The Journal of Economic History*, *7*(02), 149–159. https://doi.org/10.1017/S0022050700054279

Sensfuß, F., Ragwitz, M., & Genoese, M. (2008). The merit-order effect: A detailed analysis of the price effect of renewable electricity generation on spot market prices in Germany. *Energy Policy*, *36*(8), 3086–3094.

Sharma, S. (2000). Managerial interpretations and organizational context as predictors of corporate choice of environmental strategy. *Academy of Management Journal*, *43*(4), 681–697.

Simon, H. A. (1965). *Administrative behavior* (Vol. 4). Cambridge University Press. Retrieved from http://journals.cambridge.org/production/action/cjoGetFulltext?fulltextid=5378404

Simon, H. A. (1979). Rational decision making in business organizations. *The American Economic Review*, *69*(4), 493–513.

Slaughter, R. A. (1993a). Looking for the real ‘megatrends.’ *Futures*, *25*(8), 827–849.

Slaughter, R. A. (1993b). Looking for the real ‘megatrends.’ *Futures*, *25*(8), 827–849.

Smith, A. (2007). Translating sustainabilities between green niches and socio-technical regimes. *Technology Analysis & Strategic Management*, *19*(4), 427–450.

Smith, A., Voß, J.-P., & Grin, J. (2010). Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research Policy*, *39*(4), 435–448. https://doi.org/10.1016/j.respol.2010.01.023

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

Solow, R. M. (1956). A Contribution to the Theory of Economic Growth. *The Quarterly Journal of Economics*, *70*(1), 65–94. https://doi.org/10.2307/1884513

Solow, R. M. (1957). Technical Change and the Aggregate Production Function. *The Review of Economics and Statistics*, *39*(3), 312–320. https://doi.org/10.2307/1926047

Spencer, L., Ritchie, J., Lewis, J., & Dillon, L. (2003). Quality in qualitative evaluation: a framework for assessing research evidence. Retrieved from http://dera.ioe.ac.uk/21069/2/a-quality-framework-tcm6-38740.pdf

Steinbach, A. (2013). Barriers and solutions for expansion of electricity grids—the German experience. *Energy Policy*, *63*, 224–229. https://doi.org/10.1016/j.enpol.2013.08.073

Steinhilber, S., Wells, P., & Thankappan, S. (2013). Socio-technical inertia: Understanding the barriers to electric vehicles. *Energy Policy*, *60*, 531–539. https://doi.org/10.1016/j.enpol.2013.04.076

Stern, D. I. (1993). Energy and economic growth in the USA: a multivariate approach. *Energy Economics*, *15*(2), 137–150.

Stern, N. H. (2006). *Stern Review: the economics of climate change*. London: HM Treasury.

Steunenberg, B. (2007). A policy solution to the European Union's transposition puzzle: Interaction of interests in different domestic arenas. *West European Politics*, *30*(1), 23–49. https://doi.org/10.1080/01402380601019639

Stevens, P. (2012). The 'shale gas revolution': Developments and changes. *Chatham House*, 2–3.

Stiglitz, J. (2008). Economic Foundations of Intellectual Property Rights. *Duke Law Journal*, *57*(6), 1693–1724.

Stiglitz, J. (2012). *The price of inequality*. Penguin UK.

Stockburger, C. (2016, October 9). Verbot von Diesel- und Benzinautos: Ausgebrannt. Retrieved January 29, 2017, from http://www.spiegel.de/auto/aktuell/verbot-von-benzin-autos-und-diesel-autos-ausgebrannt-kommentar-a-1115707.html

Strunz, S. (2014). The German energy transition as a regime shift. *Ecological Economics*, *100*, 150–158. https://doi.org/10.1016/j.ecolecon.2014.01.019

Sühlsen, K., & Hisschemöller, M. (2014). Lobbying the 'Energiewende'. Assessing the effectiveness of strategies to promote the renewable energy business in Germany. *Energy Policy*, *69*, 316–325. https://doi.org/10.1016/j.enpol.2014.02.018

Swan, T. W. (1956). Economic Growth and Capital Accumulation. *Economic Record*, *32*(2), 334–361. https://doi.org/10.1111/j.1475-4932.1956.tb00434.x

Swann, G. M. P. (2009). *The Economcs of Innovation: An Introduction*. Edward Elgar Publishing Ltd.

Tapscott, D. (1996). *The digital economy: Promise and peril in the age of networked intelligence* (Vol. 1). McGraw-Hill New York. Retrieved from http://http-server.carleton.ca/~aramirez/5401/BookReviews/Babu.pdf

Taylor, M. (2008). Beyond technology-push and demand-pull: Lessons from California's solar policy. *Energy Economics*, *30*(6), 2829–2854. https://doi.org/10.1016/j.eneco.2008.06.004

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, *15*(6), 285–305.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, *18*(7), 509–533.

The Economist. (2012, July). Energiewende. *The Economist*. Retrieved from http://www.economist.com/node/21559667/print

The Economist. (2014a, January). Sunny, windy, costly and dirty. *The Economist*. Retrieved from http://www.economist.com/node/21594336/print

The Economist. (2014b, September). Getting out of gas. *The Economist*. Retrieved from http://www.economist.com/node/21620080/print

The Economist. (2016a, May). Power hungry. *The Economist*. Retrieved from http://www.economist.com/news/britain/21698673-hinkley-point-nuclear-shambles-highlights-flaws-british-energy-policy-power-hungry

The Economist. (2016b, August). It's not easy being green. *The Economist*. Retrieved from http://www.economist.com/news/europe/21704819-even-new-reforms-doubts-remain-about-germanys-energy-transition-its-not-easy-being-green

The Worldwatch Institute. (2015). *State of the World 2015: Confronting Hidden Threats to Sustainability*. Island Press.

Tongur, S., & Engwall, M. (2014). The business model dilemma of technology shifts. *Technovation*, *34*(9), 525–535. https://doi.org/10.1016/j.technovation.2014.02.006

Tõnurist, P., den Besten, D., Vandeven, P., Yu, X., & Paplaityte, D. (2015). Market Liberalization and Innovation in the Energy Sector: The Case of Belgium and the Netherlands. *Administrative Culture*, *16*(2), 83–116.

Töpfer, K., Kleiner, M., Beck, U., von Dohnanyi, K., Fischer, U., Glück, A., … Vassiliadis, M. (2011). *Deutschlands Energiewende - Ein Gemeinschaftswerk für die Zukunft. Vorgelegt von der Ethik-Kommission Sichere Energieversorgung.* (Ethik-Kommission Sichere Energieversorgung im Auftrag der Bundeskanzlerin Dr. Angela Merkel). Berlin. Retrieved from https://www.bundesregierung.de/ContentArchiv/DE/Archiv17/_Anlagen/2011/07/2011-07-28-abschlussbericht-ethikkommission.pdf?__blob=publicationFile&v=4

Tripsas, M. (1997). Unraveling the process of creative destruction: Complementary assets and incumbent survival in the typesetter industry. *Strategic Management Journal*, *18*(1), 119–142.

Tripsas, M., & Gavetti, G. (2000). Capabilities, cognition, and inertia: Evidence from digital imaging. *Strategic Management Journal*, *21*(10–11), 1147–1161.

Tushman, M. L., & Anderson, P. (1986). Technological discontinuities and organizational environments. *Administrative Science Quarterly*, *31*(3), 439–465.

Tushman, M. L., & O'Reilly, C. A. (1996). The ambidextrous organizations: managing evolutionary and revolutionary change. *California Management Review*, *38*(4), 8–30.

Van den Bergh, J. C., Truffer, B., & Kallis, G. (2011). Environmental innovation and societal transitions: Introduction and overview. *Environmental Innovation and Societal Transitions*, *1*(1), 1–23.

Van der Vleuten, E., & Högselius, P. (2012). Resisting change? The transnational dynamics of European energy regimes. In G. Verbong & D. Loorbach, *Governing the Energy Transition. Reality, Illusion or Necessity. Routledge* (pp. 75–100). London: Routledge. Retrieved from https://www.researchgate.net/profile/Erik_Van_der_vleuten2/publication/262684680_Resisting_change_The_transnational_dynamics_of_European_energy_regimes/links/53f20b960cf2f2c3e7fcaf66.pdf

Verbong, G., Geels, F. W., & Raven, R. (2008). Multi-niche analysis of dynamics and policies in Dutch renewable energy innovation journeys (1970–2006): hype-cycles, closed networks and technology-focused learning. *Technology Analysis & Strategic Management*, *20*(5), 555–573.

Vernon, R. (1966). International investment and international trade in the product cycle. *The Quarterly Journal of Economics*, *80*(2), 190–207.

Viebahn, P., Nitsch, J., Fischedick, M., Esken, A., Schüwer, D., Supersberger, N., … Edenhofer, O. (2007). Comparison of carbon capture and storage with renewable energy technologies regarding structural, economic, and ecological aspects in Germany. *International Journal of Greenhouse Gas Control*, *1*(1), 121–133.

Vollebergh, H. R. J. (2007). *Differential impact of environmental policy instruments on technological change: a review of the empirical literature*. Tinbergen Institute Discussion Paper Series. Retrieved from http://repub.eur.nl/pub/10218

Von Hippel, E. (1976). The dominant role of users in the scientific instrument innovation process. *Research Policy*, *5*(3), 212–239.

Von Hippel, E. (1994). "Sticky information" and the locus of problem solving: implications for innovation. *Management Science*, *40*(4), 429–439.

Von Hippel, E. (2001). Innovation by user communities: Learning from open-source software. *MIT Sloan Management Review*, *42*(4), 82.

Von Hippel, E., Thomke, S., & Sonnack, M. (1999). Creating breakthroughs at 3M. *Harvard Business Review*, *77*, 47–57.

Voß, J.-P., Bauknecht, D., & Kemp, R. (2006). *Reflexive governance for sustainable development*. Cheltenham, UK: Edward Elgar Publishing.

Voß, J.-P., Fischer, C., Schumacher, K., Cames, M., Pehnt, M., Praetorius, B., & Schneider, L. (2003). An integrated concept for the study of transformation in electricity systems. *Frankfurt Am Main: Sozialökologische Forschung*, (TIPS Discussion Paper 3). Retrieved from http://www.tips-project.org/download/tips_innovation_paper_031217.pdf

Voß, J.-P., Smith, A., & Grin, J. (2009). Designing long-term policy: rethinking transition management. *Policy Sciences*, *42*(4), 275–302.

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society*, *9*(2), 5.

Walz, R., Schleich, J., & Ragwitz, M. (2011). Regulation, innovation and wind power technologies–an empirical analysis for OECD countries. In *Paper presented at the DIME Final Conference*. Maastricht. Retrieved from http://final.dime-eu.org/files/Walz_C5.pdf

Wangler, L. U. (2010). *Renewables and innovation: Empirical assessment and theoretical considerations* (No. 2010/002). Jena Economic Research Papers. Retrieved from http://www.econstor.eu/handle/10419/32559

Wangler, L. U. (2012). Renewables and innovation: did policy induced structural change in the energy sector effect innovation in green technologies? *Journal of Environmental Planning and Management*, *56*(2), 211–237. https://doi.org/10.1080/09640568.2012.662464

Wassermann, S., Reeg, M., & Nienhaus, K. (2015). Current challenges of Germany's energy transition project and competing strategies of challengers and incumbents: The case of direct marketing of electricity from renewable energy sources. *Energy Policy*, *76*, 66–75. https://doi.org/10.1016/j.enpol.2014.10.013

Weick, K. E. (1979). *The Social Psychology of Organizing* (2nd edition). New York: McGraw-Hill Humanities/Social Sciences/Languages.

Weinberg, A. M. (1972). Social institutions and nuclear energy. *Science*, *177*(4043), 27–34.

Weintraub, E. R. (1993). Neoclassical Economics. In *The Concise Encyclopedia of Economics* (Vol. 1st edition). Library of Economics and Liberty. Retrieved from <http://www.econlib.org/library/Enc1/NeoclassicalEconomics.html>

Welch, C., Marschan-Piekkari, R., Penttinen, H., & Tahvanainen, M. (2002). Corporate elites as informants in qualitative international business research. *International Business Review*, *11*(5), 611–628.

Westphal, L. E. (1982). *Fostering technological mastery by means of selective infant-industry protection*. World Bank. Retrieved from http://213.154.74.164/invenio/record/12683/files/westphalREP253.pdf

Wieczorek, A. J., & Hekkert, M. P. (2012). Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Science and Public Policy*, *39*(1), 74–87.

WWF. (2016). *WWF-Stellungnahme zum EEG-Referentenentwurf vom 14.04.2016*. Berlin. Retrieved from http://www.wwf.de/fileadmin/fm-wwf/Publikationen-PDF/WWF-Stellungnahme_zum_EEG-Referentenentwurf_2016.pdf

10 Appendix

Figure 24: Generic interview guide

<u>Guidelines for Qualitative Explorative Interviews</u>

About this interview guide

- This document is for the interviewer, not the interviewee!
- Interviewee will receive two pages with overview/introduction of the research and areas of the interview, similar to what was sent in the email soliciting the interview
- Interview will be conducted in the most natural language for the interviewee, in most cases German
- Semi-structured interview style is employed where order of the questions may change and questions may be added or omitted
- Archival information on the company and interviewee will be assembled prior to the interview (incl. role/CV of the interviewee, company facts and figures, relevant information from corporate website, press releases, reports and media) – questions and topics may thus be varied to include company-specific information

Concept	*Questions*
Introduction	Meet, greet and thanks for the time Overview of research and today's interview process Explanation and consent to further process 1. Audio recording of the interview (alternative: interview protocol) 2. Transcription into text format 3. Interviewee can review/alter the transcription 4. Transcription will be used for data analysis and documentation, not be included in publications 5. Everything is anonymous: name and company of will not be revealed, information will only be used in aggregated form 6. Interviewee will receive results of the dissertation after completion
Definition and corporate organization of innovation	What does innovation mean to your company? What comprises innovation? What is your role? What are your responsibilities? How are innovation activities organized (central v. decentral responsibility, strategy, coordination, portfolio management, non-technological innovations)?
Definition of Energiewende	How would you define Energiewende? What elements/aspects constitute Energiewende in your opinion? When did Energiewende start?
Attention to Energiewende	When did Energiewende become a topic on your corporate agenda/ receive management-level attention? What exactly was discussed with respect to Energiewende? When? At what level of hierarchy? How has the discussion of Energiewende at management level evolved over time?
Interpretation of Energiewende	Does your company support the vision behind Energiewende and the way it is and has been implemented? Have you perceived the politics of Energiewende to be stringent (sufficiently forceful, effective), reliable and predictable? Which aspect in particular? How did you interpret the effect on your company (positive/negative)? Again, of which aspect of Energiewende in particular? On which business area?

Effect of Energiewende on innovation (in general)	How has Energiewende affected innovation in your company? • Which aspect of Energiewende (vision, policy, trend)... • Has influenced which aspect of innovation (strategy, activities)... • How and when? • Why?
Differentiated effect across technologies	How has the effect differed across technologies? • Generation – conventional • Generation – renewables • Transmission and distribution • Energy storage/ distributed energy • Smart grid/ demand-side energy management • Energy efficiency • Carbon capture and storage
Effect of aspects of Energiewende	What effect on innovation have individual elements of Energiewende had? • Energieforschungsprogramme since 1974 • Early push for renewable energy through StrEG in the 1990s • Strong incentives for RES through EEG in 2000 and successive years and impact on market growth and size • Nuclear phase-out decision in 2000 • Extended operating periods for nuclear power plants in 2010 (Energiekonzept) • Accelerated nuclear phase-out post-Fukushima ("Energiewende") • Long term targets for RES and energy efficiency for 2020 and 2050 (Energiekonzept) • European GHG/RES/energy efficiency targets for 2020 (20/20/20; European Climate and Energy Package Dec. 2008 • European GHG/RES/energy efficiency targets for 2030 (40/27/27; European Council Oct. 2014) • European Emissions Trading Scheme (ETS) • International climate negotiations and targets (Kyoto 1990/1997 -21% for Germany) • Grid extension plans (2012 Netzausbauplan) • Other regulations (energy efficiency etc.) • Other guidelines and initiatives (Exportinitiative EE/ RES) • Manifestations of socio-technical process: Customer demand, competitor activities, supplier activities/availability of new technology, general trend, other
Effect of other trends	What effect on innovation did these other trends have? • Digitalisation/ big data • Demographic change • Urbanization/ rise of the middle class
Effect on vision and strategy	How has your company's innovation vision and strategy been affected by Energiewende? I.e. the objectives, time plans and allocation of resources across technologies etc.? • What? • When? • Which aspect of Energiewende? • Why?
Effect on search and information approach	How has your company's search and information approach for innovations been affected by Energiewende?

Effect on Research, Development and Demonstration	How have your company's RD&D activities been affected by Energiewende (rate, direction, type)? • Rate = magnitude of expenditures, e.g., € per year • Direction = area of expenditures, e.g., specific technology, product, process etc. • Type = type of R&D spend, e.g., inhouse, outsourced, cooperative or basic v. applied research How has R&D for Energiewende-relevant categories developed in the past? Are you planning to increase or decrease in the future? How does the structure of your R&D spend for Energiewende-related products look like? E.g., traditional inhouse R&D, outsourced R&D, joint RD&D with customers/suppliers, customer/supplier on-site development What determines how much your company invests in R&D in general and in R&D for Energiewende-relevant products? Would you be able to break down your R&D spend according to 1. technology, and 2. Energiewende v. non-Energiewende induced spend? How (much) of your innovation activity is later reflected in patents? *Research (basic lab research), Development (testing/small scale/piloting), Demonstration (testing/large scale/implementation plan*
Effect on Cooperation	Has your company changed its strategy and/or activities when it comes to cooperating with external parties on innovation? With what partner has your company cooperated (or is planning to cooperate) on innovations? • Supplier, Customer, Competitor, University/ research institute, Other affiliation What kind of innovation cooperations have you established (or are you planning to establish)? • Joint R&D facilities/projects, Joint demonstration projects, On site development (of plants in operation), Networking/informal exchange platforms
Effect on use of Public Funds	Have you made use of (or are you planning to make use of) any of the public funds and financial support mechanisms installed as part of Energiewende? Had there not been public financial support, would you have pursued similar innovation efforts (rate/direction/type)?
Adoption	How has your company's investment into (acquisition of) external knowledge and technology been affected by Energiewende (rate, direction, type)? • Rate = magnitude of expenditures Direction = area of expenditures, e.g., specific technology, product, process etc. • Type = type of external knowledge or technology acquired (external knowledge: Licenses, patents, trademarks; technology: Machinery) Has your company acquired external knowledge through M&A/ seed funding/ corporate venturing?
Exploration v. exploitation	How much have you invested in the expansion of production capacity for Energiewende-related products v. in innovation/ R&D? Have you experienced a tension/trade-off between investing in exploration activities such as R&D and investing in the best exploitation of your existing technology e.g., production and sales force capacity?
Crowding-out effect	Has any shift in rate/direction/type of your innovation activities towards

Product Innovations	Has your company implemented (or is planning to implement) product innovations as a response to Energiewende? *For energy utilities:* energy consulting services for households/companies, smart home applications, products with various energy mixes
Process Innovations	Has your company implemented (or is planning to implement) process innovations as a response to Energiewende? *For energy utilities:* development and implementation of virtual power plants/ distributed energy
Marketing Innovations	Has your company implemented (or is planning to implement) marketing innovations as a response to Energiewende? • Product design or packaging (incl. complementary products) • Placement (distribution channels) • Promotion (advertising, type of language) • Pricing
Organizational Innovation and Change	Which organizational units in your company had and have to innovate most as a response to Energiewende? • Strategy/Planning, R&D, Procurement/Supply Chain, Production, Marketing/Trading, Sales/Customer Services Has your company implemented (or is planning to implement) structural changes (innovations) in response to Energiewende? • New/re-structured departments, new areas, new roles, new responsibilities, dedicated task force Has your company implemented (or is planning to implement) procedural changes (innovations) in response to Energiewende? • Creativity processes, innovation time
Change Management	How (i.e. by which management and organisational methods) were the new innovations triggered by Energiewende implemented? • Leadership/ top management commitment • Clear vision/ plan/ process • Bottom-up demand for change From an innovation perspective, how successful has your company adapted to/ incorporated the novel requirements of Energiewende? Have all necessary changes been made or started? What is the best indicator to show that you have become more innovative/ innovation active?
Politics	Has Energiewende made your company and the technological value chain in the energy sector more innovative/ innovation active? How important is innovation to the success of Energiewende? Which areas (technologies/organisational structures) still require novelties? How successful has politics today supported innovation efforts/ created an environment for firms to be innovative? What else could be done?
Conclusion	Is there another topic we should cover? Who else in your company could participate in this research? Who are your top 3 technology suppliers/customers? Would they be available to participate in this research? Thanks, summary of next steps

Figure 25: Guidelines and data sheet used in interview preparation

<u>Guidelines for Pre-Interview Archival Research</u>

Content	*Source*	*Comments*
1. Information on the interviewee		
1.1. Role	Company website, Google	
1.2. CV	Company website, Google	
1.3. Dissertation topic	Company website, Google	
1.4. Involvement in innovation	Company website, Google	
2. Information on the company		
2.1. Company data • Revenue • Operating profit • Net profit • Employees • Patents • R&D spend • Founding year	Annual reports, company website	
2.2. Comments/opinions/perception of Energiewende	Company website, company reports, press releases, Google, media coverage	
2.3. Innovation strategy	Company website, company reports, press releases, Google, media coverage	
2.4. Implemented innovations	Company website, company reports, press releases, Google, media coverage	
2.5. Innovation activities	Company website, company reports, press releases, Google, media coverage	
2.6. Organizational change	Company website, company reports, press releases, Google, media coverage	

Keywords: Energiewende/ Innovation; anything else relevant to topic and research questions

Documentation

Relevant documents documented in table of contents/ downloaded/ saved to citation program

Table 17: List of interviews

#	Interviewee title[1]	Firm	Date
1-1	Head of Investor Relations and Corporate Communications	Incumbent software/IT firm	Jan. 2015
2-1	Manager Corporate Development, Strategy, Sustainability	Incumbent electrical/mechanical engineering firm	Jan. 2015
2-2	1. Head of Corporate Innovation Management 2. Head of Energy Innovations within Corporate Innovation Management	Incumbent electrical/mechanical engineering firm	Mar. 2015
3-1	Head of Corporate R&D	Incumbent national electricity supplier	Jan. 2015
3-2	Head of Innovation	Incumbent national electricity supplier	Apr. 2015
4-1	Head of Corporate Strategy, Sustainability and M&A	Incumbent regional electricity supplier	Jan. 2015
5-1	Head of Energy Economics	Incumbent regional electricity supplier	Jan. 2015
6-1	Head of Innovation Portfolio Management	Incumbent national electricity supplier	Jan. 2015
6-2	Manager Public Affairs	Incumbent national electricity supplier	Feb. 2015
7-1	Head of Innovation	Incumbent national electricity supplier	Feb. 2015
8-1	Head of Corporate Technology & Intellectual Property Management	Incumbent heating technology firm	Feb. 2015
9-1	Head of Strategy and Innovation	Transmission systems operator	Feb. 2015
10-1	Head of Corporate Research Europe	Incumbent electrical/mechanical engineering firm	Feb. 2015
11-1	Head of Sales Germany	Incumbent electrical/mechanical engineering firm	Feb. 2015
12-1	Chief Strategy Officer	Energy efficiency service provider	Feb. 2015
13-1	Head of R&D Coordination	Start-up solar technology firm	Feb. 2015
14-1	Head of Corporate Communications	Transmission systems operator	Feb. 2015
15-1	Head of Energy Economics	Incumbent regional electricity supplier	Mar. 2015
16-1	Chief Executive Officer	Start-up software/IT firm	Mar. 2015
17-1	Head of Energy Economics	Start-up national electricity supplier	Mar. 2015
18-1	Head of Corporate Development	Start-up national electricity supplier	Mar. 2015
19-1	Head of Sales and Business Development Europe	Start-up solar technology firm	Mar. 2015
20-1	Manager Clean Energy and Innovation Management	Incumbent electrical/mechanical engineering firm	Mar. 2015
21-1	Head of R&D Energy Storage	Incumbent chemicals firm	Apr. 2015
22-1	Head of Innovation	Incumbent regional electricity supplier	Apr. 2015
23-1	Site General Manager and Head of Corporate Communications	Incumbent heating technology firm	Apr. 2015
24-1	Head of Energy Innovation and Business Development	Incumbent chemicals firm	Apr. 2015
25-1	Head of Technological Development	Incumbent electrical/mechanical engineering firm	Jun. 2015
26-1	Head of Energy Management Head of Corporate Technology Services	Incumbent chemicals firm	Jun. 2015
27-1	Head of Corporate Development and Communications, Deputy CEO	Start-up solar technology firm	Jun. 2015

[1] Some titles were adjusted to conceal the identity of the firm interviewed

Table 18: Overview of findings

Innovation activity	What		When	Who		Why									
	Subject	Dynamic	Time frame	Industry position	Value chain position/ sector	Energiewende policy mix					Confounding factors				
						Vision and strategy	Tech push	Demand pull	Systemic	Process	Market aspects & industry dynamics	Non-German environmental policy	Landscape events and developments	Resources, capabilities and cognition	Other
Exploration, development and implemen-tation	**Renewable energy generation and supply**	**Early development and retreat to niche**	1970s-1990s	• Incumbent • Start-up	• Energy tech. firms • Electricity suppliers		• Public R&D funds				• Higher energy prices (oil crisis) (!)		• Pro-environmental public opinion	• Pro-environmental corporate attitude (start-ups)	
		Market growth and mainstreaming	~2000-~2010	• Incumbent • Start-up	• Energy tech. firms • Electricity suppliers	• Long term targets (emission reductions, RES) • Nuclear exit decision 2000		• RES FIT (EEG) (!)	• Guaranteed grid access and priority for RES (EEG)		• Global demand growth & market potential (!) • Availability of RES tech. from start-ups/niche players	• Global environmental policy (targets, RES deployment policies)	• Pro-environmental public opinion	• Complementary assets/capabilities • Bias (conventional large-scale generation)	
	Conventional generation and supply	**Exploration of carbon capture, utilization and storage**	~2005-~2012	• Incumbent • Start-up	• Energy tech. & materials firms • Electricity suppliers	• Long term targets (emission reductions, RES)	• Public R&D funds	• Standards (CCS)			• Global demand growth & market potential (!)	• EU environmental policy (EU ETS, public R&D funds) • Global environmental policy (carbon markets, carbon taxes)	• Pro-environmental public opinion	• Complementary assets/capabilities • Bias (conventional large-scale generation)	Technological difficulties with CCS
	Energy consumption and efficiency	**Improving the energy efficiency of products and processes**	1970s-1990s	• Incumbent	Energy tech. firms	• Long term targets (emission reductions, energy efficiency)	• Public R&D funds				• Higher energy prices (oil crisis) • Customer demand for more energy-efficient products (!) • Firm-internal demand for more energy-efficient processes and operations (cost reductions)	• EU environmental policy (public R&D funds)	• Pro-environmental public opinion		
			~2005-present	• Incumbent • Start-up	• Energy tech. & materials firms • Electricity suppliers	• Long term targets (emission reductions, energy efficiency)	• Public R&D funds	• Standards (energy efficiency)			• Higher energy prices incl. CO2 • Customer demand for more energy-efficient products • Firm-internal demand for more energy-efficient processes and operations (cost reductions)	• EU environmental policy (targets, standards, public R&D funds)	• Pro-environmental public opinion		
		Energy efficiency as a service business	~2005-present	• Incumbent • Start-up	• Energy tech. firms • Electricity suppliers	• Long term targets (emission reductions, energy efficiency)		• Standards (energy efficiency)			• Higher energy prices incl. CO2 • Customer demand for more energy-efficient products	• EU environmental policy (targets, standards)		• Complementary assets/capabilities	
	Smart grid and energy management	**Managing grid capacity and utilization and improving grid technology**	~2005-present	• Incumbent • Start-up	• Energy tech. & materials firms • TSOs/DSOs		• Public R&D funds	• RES FIT (EEG) (indirect via systemic change)	• Mandate to provide grid access and secure energy (TSOs/DSOs) • Guaranteed grid access and priority for RES (EEG)		• Customer demand (from TSOs/DSOs) for grid improvements • Competitor activities intra-industry and from other industries	• EU environmental policy (public R&D funds)	• Electricity black-outs		Systemic change
		Supply side energy management	~2010-present	• Incumbent • Start-up	• Energy tech. firms • Electricity suppliers			• RES FIT (EEG) (indirect via systemic change)	• Penalties to electr. suppliers for non-compliance w/ grid planning • Guaranteed grid access and priority for RES (EEG)		• Customer demand (from TSOs/DSOs) for integrated management and marketing of decentral generation capacity • Fluctuating electricity markets with arbitrage potential • Competitor activities intra-industry and from other industries			• Complementary assets/capabilities	Systemic change
		Demand side energy management	~2010-present	• Incumbent • Start-up	• Energy tech. firms • Electricity suppliers			• RES FIT (EEG) (indirect via systemic change)	• Penalties to electr. suppliers for non-compliance w/ grid planning • Guaranteed grid access and priority for RES (EEG)		• Customer demand to ease pressure on grid by shifting demand • Fluctuating electricity markets with arbitrage potential • Competitor activities intra-industry and from other industries	• EU environmental policy (smart meters)			Systemic change
	Energy storage	**Improvement and sytemic integration of energy storage technology**	~2010-present	• Incumbent • Start-up	• Energy tech. & materials firms • Electricity suppliers, TSOs/DSOs		• Public R&D funds	• RES FIT (EEG) (indirect via systemic change)	• Penalties for grid fluctuations • Guaranteed grid access and priority for RES (EEG)		• Customer demand to ease pressure on grid by shifting demand	• EU environmental policy (public R&D funds)			Systemic change

Innovation activity	What		When	Who		Why									
	Subject	Dynamic	Time frame	Industry position	Value chain position/ sector	Energiewende policy mix					Confounding factors				
						Vision and strategy	Tech push	Demand pull	Systemic	Process	Market aspects & industry dynamics	Non-German environmental policy	Landscape events and developments	Resources, capabilities and cognition	Other
Adoption		**Expansion of generation portfolio to renewable energy**	~2000-~2010	• Incumbent • Start-up	• Electricity suppliers	• Nuclear exit decision 2000		• RES FIT (EEG)		Political pressure		• Global environmental policy (RES deployment)	• Pro-environmental public opinion	• Complementary assets/capabilities • Bias (conventional large-scale generation)	
		Energy-efficient modernization of generation portfolio and assets	~2005-~2010	• Incumbent	• Energy tech. firms • Electricity suppliers	• Long term targets (emission reductions)		• Standards (energy efficiency)			• Higher energy & CO2 prices	• EU environmental policy (EU ETS, standards)	• Pro-environmental public opinion	• Bias (conventional large-scale generation)	
		Modernization and expansion of electricity grids	~2005-present	• Incumbent	• TSOs/ DSOs			• RES FIT (EEG) (indirect via systemic change)	• Mandate to provide grid access and secure energy (TSOs/DSOs) • Regulation affecting investment volumes of TSO/DSO						Systemic change
Organization		**Corporate vision and strategy**	~2005-~2010	• Incumbent	• Energy tech. & materials firms • Electricity suppliers	• Long term targets (emission reductions)					• Customer demand for more environmental consciousness	• Global environmental policy (targets, climate change debate)	• Pro-environmental public opinion (esp. regarding climate change)		
		Structural organizational change	~2000-present	• Incumbent • Start-up	• Energy tech. & materials firms • Electricity suppliers			• RES FIT (EEG) (indirect via systemic change)			• Customer demand for more environmental consciousness and respective visibility of such products			• Complementary assets/capabilities (pooling)	Systemic change
		Cultural change	~2011-present	• Incumbent	• Energy tech. & materials firms • Electricity suppliers			• RES FIT (EEG) (indirect via systemic change)							Systemic change
		Collaboration	~2005-present	• Incumbent • Start-up	• Energy tech. & materials firms • Electricity suppliers			• RES FIT (EEG) (indirect via systemic change)					• Digitalization	• Complementary assets/capabilities (growth, risk reduction)	
	Business models	**Asset light green electricity marketing**	~1997-~2000	• Start-up	• Electricity suppliers				• Liberalization of electricity markets		• Customer demand for GHG and nuclear free electricity	• EU energy policy (liberalization)		• Pro-environmental corporate attitude • Bias (owner-operator-supplier	
		Complementary energy services	~2000-~2010	• Incumbent	• Electricity suppliers				• Liberalization of electricity markets					• Complementary assets/capabilities	
		Business model experimentation due to the energy transition	~2012-present	• Incumbent • Start-up	• Electricity suppliers	• Accelerated Energiewende 2011		• RES FIT (EEG) (indirect via systemic change)			• Lower wholesale electricity price (!) • Competitor activities intra-industry and from other industries		• Digitalization	• Bias (owner-operator-supplier business model)	Systemic change

(!) = most important influence

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