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Do policy mix characteristics matter for low-carbon innovation? A survey-based exploration for renewable power generation technologies in Germany

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Abstract

Policy mixes may play a crucial role in redirecting and accelerating innovation towards low-carbon solutions, thus addressing a key societal challenge. Towards this end, the characteristics of such policy mixes have been argued to be of great relevance, yet with little empirical evidence backing up such claims. In this paper we explore this link between policy mix characteristics and low-carbon innovation, using the research case of the transition of the German electricity system towards renewable energy. Our empirical insights are based on an innovation survey among German manufacturers of renewable power generation technologies which builds on the Community Innovation Survey, but which we adjusted to better capture companies' perceptions of the policy mix. Employing a bivariate Tobit model we find that companies' perceptions regarding the consistency and credibility of the policy mix are positively associated with the level of their innovation expenditures for renewable energies, and this positive link intensifies when considering the mutual interdependence of these policy mix characteristics. In contrast, we find no support for such a direct link for the comprehensiveness of the instrument mix or the coherence of policy processes. These findings suggests that future research on low-carbon and eco-innovation more broadly should pay greater attention to the characteristics of policy mixes, rather than focusing on policy instruments only. It also implies a need to rethink the consideration of policy in innovation surveys to enable better informed policy advice regarding the greening of innovation.

Keywords: policy mix, credibility, consistency, coherence, comprehensiveness, eco-innovation, renewable energy, sustainability transition, decarbonization

1 Introduction

Achieving the ambitious decarbonization targets of the Paris Agreement agreed upon at COP21 in December 2015 requires the redirection and acceleration of innovation towards low-carbon solutions. As recognized by the OECD this implies "*we need to ensure that we are talking about making all innovation green! To do that requires widespread adoption of the right support frameworks combined with clear and credible government commitments so that green considerations are incorporated into innovation policy settings from the outset.*" (Guerría, 2016, p. 36). Similarly, the sustainability transitions literature calls for policy mixes which address the various market, structural and transformational system failures hindering the aspired decarbonization of the economy (Jacobsson and Bergek, 2011; Weber and Rohracher, 2012; OECD, 2015; OECD/IEA/NEA/ITF, 2015; Rogge and Reichardt, 2016). However, there remain large discrepancies between these acknowledgements of the importance of greening innovation and the need for policy mixes, and the mainstreaming of such thinking into innovation policy and research.

For such an endeavour, much can be learned from the literature on eco-innovation which has long recognized the important role of policy in spurring green innovation (Rennings, 2000; Jaffe et al., 2002; OECD, 2011; Bergek and Berggren, 2014; Díaz-García et al., 2015). Building on the notion of "double externalities" over the past two decades both quantitative and qualitative studies have provided important insights into the measurement and determinants of eco-innovation (del Río González, Pablo, 2009; OECD, 2009; Kemp and Pontoglio, 2011; Bergek and Berggren, 2014). One of the key policy insights of this literature is that rather than the instrument type it is the design of the policy instrument that is decisive for eco-innovation, with stringency standing out as particularly relevant design feature (Frondel et al., 2008; Ghisetti and Pontoni, 2015). In addition, it has been acknowledged that eco-innovation benefits from the combination of demand pull and technology push instruments (Peters et al., 2012; Costantini et al., 2015, Schleich et al., 2017) as well as systemic instruments (Smits and Kuhlmann, 2004; Taylor, 2008; Wieczorek and Hekkert, 2012; Cantner et al., 2016). However, broader policy mix aspects and in particular characteristics such as credibility, consistency or comprehensiveness have so far only rarely been addressed, with some notable recent advances using case studies and patent data (Reichardt and Rogge, 2016; Costantini et al., 2017).

Studies utilizing survey data have to the best of our knowledge not yet included such a broader policy mix thinking into their questionnaire design and analysis, despite the methodological advantage of gathering more detailed policy data alongside other innovation measures. Yet, a recent review of econometric survey analysis shows that regulation is one of the few generally statistically significant determinants of eco-innovation (del Río et al., 2016). Because of limited data availability, however, the econometric models may capture the effect of a particular policy instrument by including a dummy variable only (del Río et al., 2016). In contrast, some specialized eco-innovation surveys have provided more in-depth insights on the link between policy and green innovation, such as through the inclusion of environmental policy stringency as a policy variable (Johnstone, 2007; Kammerer, 2009) or the simultaneous consideration of long-term targets and several climate, energy and innovation policy instruments (Schmidt et al., 2012b). In contrast, large-scale innovation surveys, such as the Community Innovation Survey (CIS) conducted within the European Union, tend to have a very limited coverage of policy, and often only focus on public support for research and development (R&D), appropriation methods or obstacles to innovation. Similarly, the Oslo Manual, which provides guidelines for innovation surveys, puts little emphasis on the measurement of policy as a determinant for innovation, despite stressing the importance of innovation survey data for guiding policy (OECD, 2005).

A notable exception to this apparent neglect of policy in mainstream innovation surveys is a question block on eco-innovation which was introduced as supplement to the 2008 CIS wave, following suggestions of the 'Measuring Eco-Innovation' (MEI) project (Kemp and Pearson, 2007). Since then, for participating countries, such as Germany, Spain, Italy or France, information on eco-innovation and its drivers has been collected and analysed in these large-scale surveys, with (environmental) policy being explicitly included. As key data source this has enabled a better understanding of the determinants of eco-innovation in general, and the role of policy in particular (Rennings and Rammer, 2011; Horbach et al., 2013; Borghesi et al., 2015). However, these studies have not been able to address wider policy mix concerns, which is unlikely to change with the 2014 CIS wave, as the policy-related questions in the revamped eco-innovation block have largely remained unchanged (Rammer et al., 2016). Yet, given the urgency of the climate change and other sustainability challenges we argue that the time has come to rethink how to better capture the link between policy and green innovation in innovation surveys.

In this paper, we take a first step in addressing this current shortcoming in mainstream innovation surveys by using the example of the decarbonization of the energy system for which renewable energies play a key role (Jacobsson and Bergek, 2004; Gallagher et al., 2012; Negro et al., 2012). Given the supplier dominated innovation pattern of the energy sector we focus on manufacturers of renewable power generation technologies (Pavitt, 1984; Rogge and Hoffmann, 2010). We limit the scope of our explorative study to the German *Energiewende* because of its ambitious targets and rich policy mix, as well as its pioneering role in renewable energy innovation (Bruns et al., 2011; Pegels and Lütkenhorst, 2014; Strunz, 2014; Quitzow et al., 2016). Building on recent qualitative insights on the impact of policy mix characteristics for innovation in the case of offshore wind (Reichardt and Rogge, 2016) the aim of our paper is to quantitatively explore this link using survey data. In particular, we are interested in answering the research question whether policy mix characteristics indeed matter for innovation, and focus here on the four characteristics proposed by Rogge and Reichardt (2016), namely consistency, credibility, comprehensiveness and coherence (4Cs). For this, we build on the CIS questionnaire but redesign it to explicitly capture the policy mix and low-carbon innovation. The resulting unique data set collected in 2014 allows us to econometrically analyze the link between policy mix characteristics and green innovation, thereby supplementing patent-based evidence of Costantini et al. (2017) suggesting a key role of the comprehensiveness and balance of instrument mixes for patenting activity in energy efficiency. While our study concerns Germany, its insights provide research and policy implications also of relevance for other regions and countries interested in harnessing the low-carbon market opportunities arising from the Paris Agreement, such as China, California, or the UK (Cai and Zhou, 2014; Diaz Anadon et al., 2014; Uyarra et al., 2016).

The remainder of the paper is structured as follows. In section 2 we develop our analytical framework from the literature and derive propositions regarding the link between policy mix characteristics and innovation. Section 3 presents the research case of the German *Energiewende*. This is followed by section 4 which introduces our methodological approach in terms of sampling, survey design, data collection and data analysis. In section 5 we present our results which we then discuss in section 6. We conclude with policy and research implications in section 7.

2 Literature background and propositions

Our interdisciplinary framework draws on environmental economics, innovation studies and policy analysis and follows the typical differentiation between firm-external and firm-internal determinants of eco-innovation (del Río González, Pablo, 2009). Regarding firm-external determinants we focus on the influence of the policy mix, thereby extending earlier work which has highlighted the role of environmental regulation for eco-innovation (del Río et al., 2016). In particular, we are interested in answering the research question whether policy mix characteristics matter for low-carbon innovation, and focus here on the four proposed by Rogge and Reichardt (2016), namely consistency, credibility, comprehensiveness and coherence (4Cs). Such characteristics describe the nature of policy mixes and have been argued to impact the performance of policy mixes regarding standard assessment criteria, such as effectiveness and efficiency. As different bodies of literatures have used these terms quite differently, here we follow the definitions suggested by Rogge and Reichardt (2016) within their interdisciplinary policy mix framework (see Table 1).

Table 1: Definitions of the policy mix characteristics analyzed in this study

Characteristic	**Definition**
Consistency	"…captures how well the elements of the policy mix are aligned with each over, thereby contributing to the achievement of policy objectives. It may range from the absence of contradictions [weak consistency] to the existence of synergies [strong consistency] within and between the elements of the policy mix." (p. 1626)
Credibility	"… the extent to which the policy mix is believable and reliable [..], both overall and regarding its elements and processes." (p. 1627)
Comprehensiveness	"…captures how extensive and exhaustive its elements are [of the policy mix] and the degree to which its processes are based on extensive decision-making" (p. 1627)
Coherence	"…referring to synergistic and systematic policy making and implementation processes contributing – either directly or indirectly – towards the achievement of policy objective." (p. 1626)

Source: Rogge and Reichardt (2016)

First, regarding the *consistency* of the elements of the policy mix we distinguish three different levels (Rogge and Reichardt, 2016). The first level concerns the consistency of the policy strategy and assesses the alignment of policy objectives, such as cost-effective deployment of renewables or the establishment of domestic manufacturing capacity, thereby capturing if these can be achieved simultaneously without significant trade-offs. Second, the consistency of the instrument mix captures whether instruments reinforce or instead undermine each other (Kern and Howlett, 2009). Third, the overall policy mix consistency captures the consistency of the instrument mix with the policy strategy, implying that they work together in a unidirectional or mutually supportive fashion (Howlett and Rayner, 2013).[1] The literature suggests that a higher degree of consistency makes policy mixes more effective, but also acknowledges that there are

1 The first and third level of policy mix consistency relates to what the policy design literature is referring to as goal 'coherence' and 'congruence' of goals and instruments (Howlett and Rayner (2013), Kern and Howlett (2009)).

limits to policy mix consistency, particularly in transition processes (Quitzow, 2015a; Rogge and Reichardt, 2016). The role of consistency for innovation has so far been mainly empirically explored through qualitative studies. For the case of low-carbon innovation in the UK, Uyarra et al. (2016) find that the complexity and inconsistency of the UK innovation policy mix creates uncertainty among companies, thereby hampering private sector investment. Similarly, for the case of offshore wind in Germany Reichardt and Rogge (2016) identify consistency as a key policy mix characteristic explaining innovation activities of companies in the sector. They find that the consistency of the instrument mix, e.g. between feed-in tariffs and grid access regulation, is particularly important for adoption decisions. In contrast, the overall consistency of the policy mix, i.e. that the long-term target is substantiated by corresponding instruments, appears as particularly crucial for research, development and demonstration (RD&D). This leads us to postulate a positive link between consistency and innovation.

Proposition 1: The higher the consistency of the policy mix, the higher the level of innovation.

Proposition 1.1: The higher the consistency of the policy strategy (first level policy mix consistency), the higher the level of innovation.

Proposition 1.2: The higher the consistency of the instrument mix (second level policy mix consistency), the higher the level of innovation.

Proposition 1.3: The higher the consistency of the policy strategy with the instrument mix (third level policy mix consistency), the higher the level of innovation.

A second key characteristic of policy mixes is their *credibility* which also may be key for innovation and can be influenced in a number of ways (Rogge and Reichardt, 2016). For the case of energy evidence suggests that the perception of the credibility of political commitments can influence investment and social outcomes (Nemet et al., 2014). Indeed, the role of the credibility of climate policy has seen growing interest in climate economics, building on related work in monetary, fiscal and trade policy (Helm, 2003; Bosetti and Victor, 2011; Kang and Létourneau, 2016; Nemet et al., 2017). For example, in a model based assessment Bosetti and Victor (2011) show that the lack of regulatory credibility has massive implications on costs because “firms and other agents become short-sighted and unable to make optimal investments in research and development as well as long-lived technologies” (p. 1). Similarly, employing real options theory to model electric power plant investments, Kang and Létourneau (2016) find that the risk of government credibility may lead to more investment in “less green” plants. Broadening this out to the overarching policy mix the qualitative study of Reichardt and Rogge (2016) on offshore wind in Germany delivers further insights into the effect credibility may have on investment and innovation decisions. They find that the credible policy strategy with ambitious, stable and technology-specific long-term targets stimulated firms' RD&D, and that the credibility of the overall policy mix facilitated adoption decisions. Similarly, a study of the corresponding technological innovation system of offshore wind finds that policy mix credibility has a positive effect on guidance of the search, thereby stimulating innovation activities and overall system development (Reichardt et al., 2016). These insights lead us to postulate a positive link between policy mix credibility and innovation.

Proposition 2: The higher the credibility of the policy mix, the higher the level of innovation.

Recent qualitative research has also pointed to a *link between credibility and other policy mix characteristics, in particular consistency*. For example, company case studies of German power generators, technology providers and project developers showed that the credibility of long-term climate targets was significantly increased by being implemented through the EU emissions trading system, thereby increasing policy mix consistency which together contributed to corporate vision changes (Rogge et al., 2011). In addition, for the case of Ontario and Norway White et al. (2013) found that through abrupt changes in energy policy governments lost political credibility which had negative impacts on low-carbon investments. White et al. stress that it is not temporal inconsistency per se which matters, but rather that the manner in which policies are changed is the issue. Another example is provided by Uyarra et al. (2016) which for the case of the UK revealed the importance of credibility as well as stability and communication for stimulating innovation activities. Given the various policy changes the policy environment was found to lack consistency and strong signals about priorities, thereby hampering private investments. Finally, for offshore wind in Germany Reichardt and Rogge (2016) find that a high level of policy mix credibility alleviates some of the negative effects of inconsistencies in the mix. We therefore hypothesize that there is some interaction effect between policy mix credibility and consistency, where higher levels of credibility seem to be able to offset inconsistencies in the mix.

Proposition 3: The innovation impact of policy mix credibility is higher for lower levels of policy mix consistency, and vice versa.

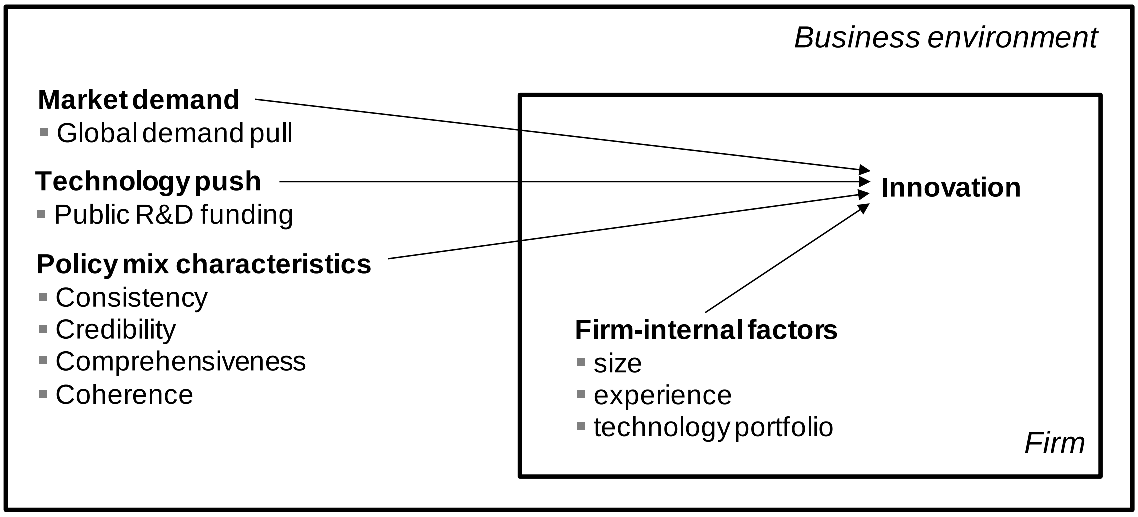
Third, regarding the *comprehensiveness* of the instrument mix it has been argued that the elimination of multiple barriers facing renewable energy and energy efficiency requires the implementation of several policy instruments in a synergistic manner (Sovacool, 2009). Based on expert interviews Sovacool argues that only through complementary instrument mixes the full potential of renewables and energy efficiency can be realized. Similarly, but focusing on invention, the patent-based analysis of energy efficient technologies for the residential sector covering 23 OECD countries by Costantini et al. (2017) shows that the comprehensiveness of the instrument mix enhances innovation performance. However, they also find evidence for a threshold of the number of policy instruments included in the mix beyond which negative interaction effects may reduce the effectiveness of the policy mix in stimulating eco-innovation. In sum, we hypothesize a positive link between comprehensiveness of the instrument mix and innovation.

Proposition 4: The higher the comprehensiveness of the instrument mix, the higher the level of innovation.

Finally, by including the *coherence of policy processes* we aim to investigate the link between synergistic and systematic policy processes and innovation. The underlying assumption is that designing effective policy mixes requires systematic capabilities of policy makers as basis for more coherent policy making and implementation (Jacobsson and Bergek, 2011). For example, Quitzow (2015a) argues that governments require advanced organizational capacities, such as the ability to manage interfaces, assemble knowledge from diverse sources and establish constructive dialogues with all relevant stakeholder groups. This need for strategic intelligence required for facilitating change has also been discussed in the context of systemic instruments (Smits and Kuhlmann, 2004). In addition, studies have identified multiple structural and procedural mechanisms which can strengthen policy coherence, such as strategic planning, communication and coordination (OECD, 1996, 2001; Ashoff, 2005; Den Hertog and Stroß, 2011). Of these, policy coordination has increasingly been discussed in the context of policy mixes (Magro et al., 2014), both giving its potential to align tasks and efforts of the public sector (Bouckaert et al., 2010) but also recognizing its limits (Flanagan et al., 2011). However, the direct link between the coherence of policy processes and innovation has received little attention in empirical work. Qualitative evidence for the case of offshore wind in Germany suggests a positive effect of stakeholder participation and a negative effect of muddling through and uncertainties arising from adaptive policy processes for innovation system functioning and performance (Reichardt et al., 2017). Jänicke et al. (2000) have previously highlighted this importance of the policy style for innovation. They identified features such as dialogue and consensus, reliability and continuity, or openness and flexibility as innovation-friendly. Henceforth, we postulate that more synergistic and systematic policy processes positively contribute to innovation.

Proposition 5: The higher the coherence of policy processes, the higher the level of innovation.

Figure 1: Analytical framework combining firm-external and firm-internal factors



Source: Own

Beyond policy mix characteristics we also include *technology push and demand pull* as classical determinants of innovation in our analytical framework (Di Stefano et al., 2012). Given the strong relevance of policy in the context of low-carbon innovation we focus on policy-driven technology push and demand pull, similarly to what has been referred to as regulatory push and pull in the eco-innovation literature (Horbach, 2008). The extant empirical analyses typically find that both types of instruments matter for green innovation and work best in tandem (Schmidt et al., 2012b; Veugelers, 2012; Costantini et al., 2015; Schleich et al., 2017). However, while the demand pull effect for export-oriented industries seems to be resulting as a combination of demand at home and abroad, for technology push this positive effect seems to arise from public R&D support from the home market only (Peters et al., 2012; Dechezleprêtre and Glachant, 2014).

Turning to the firm-internal determinants of innovation we draw on insights from evolutionary economics and the resource based view of the firm (Nelson and Winter, 1982; Wernerfelt, 1984; Barney, 2001). Since firm resources, capabilities and competences matter for innovation, we include three key firm characteristics in our analytical framework (Teece et al., 1997; Helfat et al., 2007; del Río et al., 2015). The first concerns *firm size* which has typically been found to positively impact eco-innovation (Kesidou and Demirel, 2012; del Río et al., 2016). We also include *experience* of the firm with green technologies in our framework to provide an aggregated factor capturing accumulated firm resources as well as technological and organizational capabilities in the respective technology (Kammerer, 2009; Horbach et al., 2012).[2] Finally, our framework considers the firm's *technology portfolio* to control for differences between renewable energy technologies (Schmidt et al., 2012a; Huenteler et al., 2016).

3 Research Case

We have chosen to focus on innovation in renewable energy in Germany for three main reasons. First, we focus on renewable energy innovation as it is widely acknowledged that renewable energies, whose costs have come down massively through green innovation, will play a key role in decarbonizing the global energy system (IRENA, 2013; IEA and IRENA, 2017). Second, we use the case of the *Energiewende* as Germany has implemented a rich policy mix with an ambitious policy strategy, including the long-term target of a share of at least 80% of electricity generated from renewable energies and reduction of greenhouse gas emissions by 80% by 2050. These targets are implemented through various instruments, such as the German Renewable Energy Sources Act (EEG) introduced in 2000 or dedicated public support for R&D facilitating the decarbonization of the energy system (BMWi and BMU, 2010; BMWi, 2015, 2016b). Finally, given that innovation in the power sector has been dominated by suppliers we focus on innovation activities of manufacturers of renewable power generation technologies, with Germany having a strong and export-oriented manufacturing base (Pavitt, 1984; Rogge and Hoffmann, 2010).

The German *Energiewende* has been subject to substantive research with a variety of different disciplinary, methodological approaches and analytical perspectives (Gawel et al., 2013; Smith Stegen and Seel, 2013; Strunz, 2014; Kungl, 2015; Geels et al., 2016; Hermwille, 2016; Quitzow et al., 2016; Schmid et al., 2016; Kuzemko et al., 2017; Matthes, 2017; Schmid et al., 2017). Several studies have previously explored the link between policy and innovation, typically focusing on the role of the EEG as core instrument in Germany's instrument mix, and specifically analyzing its design and co-evolution with technological and wider socio-technical change (Grau, 2014; Hoppmann et al., 2014; Lauber and Jacobsson, 2016). Attention has also been devoted to technology-specific analyses, such as for solar PV (Hoppmann et al., 2013; Richter, 2013b; Quitzow, 2015b) or wind (Richter, 2013a; Reichardt et al., 2017; Schleich et al., 2017). In particular, for the case of offshore wind, Reichardt et al. have addressed the role of

2 We refrain from using firm age as a factor reflecting the accumulation of internal capabilities as firm age would not capture the diversification of incumbent firms into green technologies. Arguably, this is one reason for the inconclusive empirical findings on the influence of firm age on green innovation (del Río et al. (2016).

the broader policy mix for green innovation, and highlighted the relevance of policy mix characteristics (Reichardt et al., 2016; Reichardt and Rogge, 2016). Yet, to our knowledge, no quantitative study has yet explicitly addressed the role of the broader policy mix and its characteristics for innovation activities of firms by means of survey data.

While analysis of German CIS data on eco-innovation is abundant (Horbach, 2008), dedicated company surveys addressing the link between policy and low-carbon innovation in the German energy sector tend to be rare, and to the best of our knowledge mainly concern two studies. First, our work is related to a study by Schmidt et al. (2012b) whose cross-country online survey (conducted in 2009) included, among others, German manufactures of power generation technologies (in total, responses from 136 of 1086 contacted technology providers in 7 EU Member States, with 38% of responses from Germany). However, while the survey included technology specific support instruments as policy mix components, it mainly focused on the role of the EU emission trading system (EU ETS) and long-term climate targets for promoting green innovation and did not follow a conventional innovation survey questionnaire. Comparison of findings with our study is further limited, since the analysis by Schmidt et al. includes 65 power generators (49% of these from Germany). For non-emitting technologies the study finds that firms' perceptions of long-term climate targets, technology policies and expectations for the third phase of the EU ETS are relevant for firms' R&D decisions. Second, in terms of the sample our survey most closely resembles the work of Doblinger et al. (2015), which relies on responses of 140 out of 1208 contacted CEOs of manufacturers and project developers active in renewable energies in Germany in 2012. The study focuses on policy in terms of the perceived relevance of demand-pull policies (EEG, financial support, renewable energy goals) and regulatory uncertainty for firm behavior, but its analysis covers a different aspect of corporate innovation than our study. Their findings indicate a negative link with innovativeness and partly with risk taking, implying that stronger demand pull instruments were found to reduce firm's execution of high risk R&D projects in favor of smaller improvements, which was reinforced by perceived higher levels of regulatory uncertainty.

The year before we fielded our survey was marked with a relatively high level of regulatory uncertainty regarding the further development of the EEG which was due to be amended in 2014. After the Fukushima accident and the resulting reinstatement of the nuclear phase-out until 2022 in 2011 (Hermwille, 2016) and with declining technology costs, particularly for solar PV (Hoppmann et al., 2014), the expansion of renewable energies in the German electricity system had accelerated in 2012 (BMWi, 2015). The resulting increases in the levy for the EEG surcharge led to debates about the retrospective adjustment of previously guaranteed feed-in tariffs (set for 20 years) which prior to that had been unthinkable. While the suggestions of the Federal Ministers of the Environment (Altmaier) and Economics (Rösler) were not implemented, they may still have left some marks on the perceived predictability and associated investment security of the EEG as core demand pull instrument. In addition, given the federal elections in the fall of 2013 the next regular reform of the EEG was postponed until a new government coalition had been formed, leading to considerable uncertainty about the future of the EEG and the ambition of the *Energiewende* and thus the broader policy mix more generally. Eventually, the new Grand Coalition government of CDU/CSU and SPD under Angela Merkel merged all *Energiewende* related activities under the roof of the Economics Ministry, leading to institutional reorientation and initial uncertainty. This new Federal Ministry of Economics and Energy (led by Gabriel, the former Minister of the Environment) published first pillars of the revision of the EEG (also dubbed as EEG 2.0) in the beginning of 2014. However, the uncertainty about the design features remained fairly high until the Federal Cabinet adopted the amended EEG on April 8, 2014, and was fully resolved after the decision of the Federal Parliament (Bundestag) on July 4, 2014. Furthermore, by 2014 federal public R&D support for green innovation had risen to above 800 Million Euro per year, with a good third of this going to renewable energy and another third to energy efficiency (BMWi, 2016b). In addition the BMWi also published a 10-point-energy agenda providing a roadmap of the planned policy changes within the *Energiewende* due under the 18th legislative term covering the period from May 2014 until December 2016, including policy mix relevant items such as the EU ETS reform, electricity market reform, transmission and distribution grids and monitoring (BMWi, 2016a). In the context of these policy mix developments the share of renewables in the German electricity system had reached 27.4% by the end of 2014, and was on track to meet the target of 40-45% by 2025 (BMWi, 2014).

4 Methodology

For our explorative study we generated a novel data set based on a survey of German manufacturers of renewable power generation technologies (see section 4.1). For this, we first compiled a company data base (see section 4.1.1), designed a questionnaire which draws upon and extends the Community Innovation Survey (see section 4.1.2) and collected company responses through a computer assisted telephone survey (CATI, see section 4.1.3). Finally, section 4.2 describes the econometric model and the variables used.

4.1 Innovation Survey

4.1.1 Construction of company data base

Given the lack of a comprehensive database of companies producing components, final products and production equipment for electricity generation based on renewable energies, we drew on multiple data sources to compile such a database of all German manufacturers active in on- and offshore wind power, solar PV, hydro, bioenergy, wave and tidal energy, geothermal energy and concentrated solar power – regardless if they have performed innovation activities in renewable energies or not. Since we focus on companies active in manufacturing this implies that our target group excludes companies solely involved in service provision, such as project management, finance, investment, installation, operation, maintenance, or sales.[3] Also, since our research question focuses on exploring the impact of the policy mix on innovation in renewable energies, we only include companies in our sample that offer products for this market.[4]

For compiling this data base we followed six steps. [5] First, we searched for manufactures in four German business directories using their predefined, technology-specific search words reflecting the main components of each technology.[6] Second, we complemented the resulting list of companies by including member companies of the German Engineering Federation (VDMA) and technology-specific associations. Third, we further supplemented this list by searching for additional manufacturers in other publicly available sources, such as manufactures listed in business fair catalogues and professional journals. Fourth, as a quality check we read companies' descriptions of activities and searched their web page to eliminate companies not fitting with our target group.

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3 In contrast, the sample compiled by Doblinger et al. (2015) not only includes suppliers and manufacturers but also project managers.

4 Our sample includes manufacturers which only sell renewables and manufacturers with a more diversified portfolio (for some manufacturers renewables only account for 1% of total turnover). Note that the impact of the policy mix on other innovation activities is beyond the scope of this paper.

5 To allow for a broader scope of companies, we decided not to use patents to identify the population. In addition, because of the time lag in patent statistics, companies which recently entered the renewable energy business would not have been included. This decision was confirmed by the answers of the companies participating in our sample. When asked how they protect intellectual property, only 43.8% indicated that they use patents, whereas other strategies such as confidentiality (71.2%) and lead-time advantages over competitors (60.4%) appeared to be more important (based on 386 responses; multiple answers were possible).

6 The four directories utilized were: „Wer liefert was" (WLW), businessdeutschland.de (BD), diedeutscheindustrie.de (DDI), and Hoppenstedt (HS).

Fifth, the resulting list was matched with sector-specific firm data bases available to the SOKO research institute conducting the survey (see 4.1.3). Finally, we used a screening question at the beginning of the survey to ensure that interviewed companies fit our search profile, otherwise they were deleted from the sample.

This way, we identified 1,092 manufacturers active in producing components, equipment and final products for renewable power generation technologies in Germany (as of 2014). These companies were invited to participate in a computer assisted telephone interview, as detailed in 4.1.3.

4.1.2 Questionnaire design

The questionnaire for our CATI survey is based on the Community Innovation Survey (CIS), as it represents an established tool for measuring corporate innovation activities. However, the CIS includes only few items on policy and does not capture policy mix thinking. Since our research focus is on the link between policy mix characteristics and innovation we designed novel questions on the policy mix and its consistency, credibility, coherence and comprehensiveness. In doing so, we first analyzed how the link between policy and innovation has been captured in past studies, particularly in the specific question block on eco-innovation in the 2008 CIS wave. We then designed supplementary questions building on the policy mix concept proposed by Rogge and Reichardt (2016). These questions ask for subjective perceptions rather than objective facts as perceptions are typically assumed to govern agents' behavior (Kaplan and Tripsas, 2008; Nooteboom, 2009; Schmidt et al., 2012b). Prior to finalizing the questionnaire, three industry experts – one each in the field of solar PV, wind power and renewable energies more generally – provided feedback on our draft question design.

The challenge for defining questions on the perceptions of companies regarding the policy mix was not only the concrete wording and establishment of items for new terms, such as coherence and credibility (see Table 2), but also the general way of how to capture the link between policy and innovation. Notwithstanding the limitations of cross-sectional data, two main options exist for exploring this link in a one-off survey. First, questions can ask directly for the relevance of political factors for past innovations, as done, for example, in the eco-innovation module of the CIS. In this case, only innovators can be analyzed (e.g. Ziegler, 2013). In addition, as innovations are typically asked for the past 3 years this assumes that respondents remember the policy mix of the past and how it has influenced past innovation decisions. Such an assumption seems unrealistic, with perceptions likely being influenced by more recent developments in the policy mix. The second and methodologically preferable option is to separately ask companies for their perception of the current policy mix. In a distinct question block, companies are asked about their current (and expected) innovation activities and/or expenditures, as it is these efforts which today's policy mix may influence and which will be largely known at the time of the survey. [7] In this paper, we pursue the second option and employ multivariate regression analysis to explore the correlations between innovation efforts and the policy mix.

Aside from the extension of the questionnaire regarding the measurement of the policy mix, our questionnaire reflects two further changes compared to the CIS. First, we tailored the questionnaire to our research case of renewable energies. For example, we asked companies for their product portfolio regarding renewable power generation technologies and their technology-specific innovation expenditures and turnover. And second, we adjusted the written language to the context of a phone interview situation. For example, we repeated the question in the middle of a long list of items to remind respondents of the original question and provided definitions for what is meant by certain terms, such as innovation.

The resulting questionnaire consists of six parts.[8] It starts with a section on general information about the company. This section draws upon the CIS but also includes questions on the firm's product portfolio regarding renewable power generation technologies and the selection of their main renewable energy technology, for which they are asked to answer the remainder of the survey to gather technology-specific information. The second part represents the novel block of questions on the policy mix which addresses companies' perception of political targets and their consistency, the consistency and comprehensiveness of the instrument mix and perceived support by various policy instruments and particular assessment of selected design features of the core demand pull instrument EEG (Renewable Energy Sources Act) and technology push support. In addition, the policy mix block includes questions about the policy making process to capture its coherence, and closes with questions on the perceived credibility of the policy mix. In line with the CIS the third part of the questionnaire asks about innovation, innovation activities and innovation expenditures – again with a focus on the main renewable power generation technology – and also includes extended ques-

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7 In contrast, resulting innovations will still be uncertain at the time of the survey, as not all of the inputs into the innovation process will lead to innovation outputs in terms of new or significantly improved products or processes.

8 Note that the following is a summary of the full innovation questionnaire. Only part of the collected information is needed for our analysis.

tions on innovation objectives and political factors for innovating or not innovating. In its fourth part, the questionnaire collects information on the market environment regarding the main renewable energy technology, such as geographic markets, input and sales price developments, and further characteristics of the competitive environment, which againlargely draw upon the CIS. The same is true for the fifth part, which captures general economic information, such as the number of employees, turnover and exports, but also addresses the expansion of production facilities. The questionnaire closes with a final section asking about the interviewees position, an open question regarding recommendations for the German government, and respondents' willingness to be approached in a follow-up survey. [9]

4.1.3 Survey implementation

The survey was implemented by an experienced research institute, SOKO.[10] After programming the questionnaire as a CATI it was tested in SOKO's facilities with two researchers being present. This live test lasted one day and covered interviews with companies active in different technologies. These pre-tests confirmed the survey design and resulted in only minor adjustments in the wording and sequence of questions and explanatory notes for interviewers.

All companies in our data base of manufactures were first contacted by a postal letter explaining the rationale and sponsor of the study. This letter also included a flyer providing further background information and a link to the overarching project website. Companies with an email address also received this information via email. After this, each company was contacted via phone to arrange for an interview appointment with the CEO or a top level manager responsible for the company's strategy, R&D or sales and with an overview of products, innovation and corporate policy. The survey was fielded from April 9, 2014 until July 22, 2014 and was answered by 390 companies, yielding a response rate of 35.7% of all German manufacturers of renewable power generation technologies.[11] On average, these phone interviews took 30 minutes.

9 The original questionnaire (and its translation into English) is available upon request.

10 http://www.soko-institut.de/

11 To test for sampling bias, the data allowed us to examine regional representativeness of our sample. The shares of participants per federal state in the sample are very close to the share of all companies per federal state in the population. Based on a χ^2 test we find no indication that our sample may suffer from a sampling bias ($p>0.99$).

SOKO anonymized all data for further processing. The descriptive results of the survey were compiled in a report which was sent to participating companies.

The results show that approx. 70% of respondents are small and medium sized enterprises (SMEs). More than half of the responses concerned solar PV (37.2%), biogas (22.3%) and onshore wind (17.4%). In addition, 71% of respondents produce components for renewable power generation technologies (see Appendix A and B). In 2013, only 11.1% of companies operated exclusively on the German market; on average 39.5% of sales were exports. Most companies were innovative, with 82% of respondents engaging in innovation activities in the last three years (2011-13). In addition, three quarters of the companies introduced product innovations in this period (75%) and two-thirds process innovations (66%) for the selected renewable power generation technology. About a quarter of the respondents received public R&D funding (from Germany or the EU) to pursue innovation activities in the main renewable power generation technology in the period 2011-13. Finally, regarding the competitive environment the most decisive characteristic was the dependence on the political framework conditions.

4.2 Econometric model

4.2.1 Dependent Variable

For our dependent variable we employ innovation expenditures as input measure of innovation. The survey asked respondents to provide estimates for innovation expenditures for the company's main renewable power generation technology in 2014 and in 2015. [12] About 25.6% (n=348) reported innovation expenditures of zero for 2014. For 2015 this share was 31.3% (n=272). Thus, for a substantial part of companies in our survey, stated innovation expenditures in one or both years is zero. We therefore employ the "corner solution" Tobit model to specify the regression equation for innovation expenditure in a particular year (*y*). Relying on the "latent variable" approach, truncation (from below) is motivated by

12 Respondents were asked about their expenditures for their innovation activities (including intramural (in-house) and extramural R&D, acquisition of machinery, equipment and software, acquisition of other external knowledge, and other preparation).

$$(1)\quad y_i^* = \beta_0 + \beta_1(TechPush_i) + \beta_2(DemandPull_i) + \beta_3(PolicyMix_i) + \beta_4(Controls_i) + u_i;\; u_i \sim N(0,\sigma^2)$$

$$y = y^* \; if \; y^* \geq 0$$
$$y = 0 \; if \; y^* < 0$$

where y_i^* stands for the latent (i.e. desired) level of innovation expenditures of firm *i* in a given year. To test our propositions and account for other factors related to firms' innovation expenditures, we include four groups of explanatory variables capturing: (i) the effects of market demand, and in particular global demand pull effects (*DemandPull*); (ii) public funding for technology push (*TechPush*); (iii) the effects of policy mix characteristics (*PolicyMix*); (iv) and the effect of control variables to reflect company- and technology-specific effects (*Controls*). Thus, positive values for innovation expenditures are observed if the latent variable y* exceeds the threshold level of zero[13]; otherwise companies chose not to spend money on innovation.

Rather than estimating (1) separately for 2014 and 2015 via univariate Tobit models, we employ a bivariate Tobit model to estimate innovation expenditure equations, where the error terms capture possible correlations between innovation expenditures in different years. That is, the use of univariate Tobit models could lead to biased and inconsistent parameter estimations (Greene, 2012). The simulated maximum likelihood estimations are carried out with Stata 13, relying on Barslund (2009).

4.2.2 Explanatory variables

The set of explanatory variables consists of variables reflecting demand pull and technology push, policy mix characteristics, and firm-internal factors.

For *demand pull* we relied on a dummy variable *(DemandPull),* which takes on the value of one, if the respondent expected the sum of domestic sales and exports of the main technology in 2014 to be higher than in 2013, and zero otherwise. This variable can be interpreted as a proxy for the effect of global demand pull instruments because of the strong dependence of market demand for renewable power generation technologies on such instruments (Peters et al., 2012; Hoppmann et al., 2013; Dechezleprêtre and Glachant, 2014).

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13 Note that the threshold level is arbitrary since it is always possible to normalize. For example, a negative parameter estimate for β_0 would indicate a positive threshold level.

For *technology push*, we focus on public R&D funding in the home market (Peters et al., 2012) which arguably for most of the companies in our sample is Germany (n=360) and Europe (n=333). Therefore, we use the amount (in Euros) of public subsidies for R&D the company had received between 2011 and 2013 from German or EU funding bodies for the main technology (*TechPush*).

For the variables employed for policy mix characteristics we distinguish between consistency, credibility, coherence and comprehensiveness (Rogge and Reichardt, 2016). For *consistency* of the policy mix we differentiate between three levels of consistency: Our explanatory variable for the first level consistency of the policy strategy (PS) is constructed by first calculating the median value of the responses to the statement presented in Table 2. *Consistency1_PS* is coded as one, if the response category was at least as high as the median value, and zero otherwise. In the same way we calculate indicators for the second level consistency of the instrument mix (IM) (*consistency2_IM*) and third level consistency of the overarching policy mix (PM), i.e. of the instrument mix with the policy strategy (*consistency3_PM*). Thus, higher values of the consistency variables indicate higher consistency of the policy strategy, of the instrument mix, and of the instrument mix with the policy strategy.

To construct our explanatory variables capturing *credibility* (and to allow for a parsimonious model specification) we first conducted a standard principal component factor analysis (using varimax rotation) on the items shown in Table 2 under the subheading credibility (Cronbach's alpha = 0.81, indicating good scale reliability). As a result of the factor analysis, two factors were kept (with eigenvalues exceeding 0.9) – with policy mix credibility at national level explaining 50% of the total variance and policy mix credibility at subnational level (i.e. Federal states and municipalities) explaining 17%, respectively. Based on the factor loadings, we then construct two indicators named *Credibility_national* and *Credibility_subnational by* taking the means of the binary variables of the individual items. These binary variables were coded as one, if the response category was at least as high as the median value, and zero otherwise.

Our explanatory variables for the *coherence* of policy processes were constructed in a similar way as for credibility. Based on the results of a standard principal component factor analysis (using varimax rotation) on the items shown in Table 2 under the subheading coherence we keep two factors, explaining 47% (informational coherence) and 14% (procedural coherence) of the total variance, respectively (Cronbach's alpha = 0.82). We then construct two indicators named *Coherence_informational* and *Coherence_procedural*. To do so we again take the mean of the binary variables of the individual items. Again, binary variables were coded as one, if the response category was at least as high as the median value, and zero otherwise.

Finally, our explanatory variable reflecting the *comprehensiveness* of the instrument mix was constructed in the same manner as the consistency variables. That is, we first calculated the median value of respondents' responses to the respective statement presented in Table 2 under the subheading comprehensiveness. *Comprehensiveness* is then coded as one, if the response category was at least as high as the median value, and zero otherwise. Thus, all coefficients capturing the characteristics of the policy mix are expected to exhibit a positive sign.

Table 2: Operationalization of variables for policy mix characteristics

Policy mix characteristics	**Statement** (translated from German to English) (response categories ranging from 1 (do not agree at all) to 6 (fully agree)	**Variable name**
Consistency		
1st level: consistency of the policy strategy	The planned expansion target for renewable energies in Germany up to 2025 is a good match with other energy and climate policy targets of the German government.	*Consistency1_PS*
2nd level: consistency of the instrument mix	The existing policy instruments reinforce each other in their positive effect on supporting the expansion of renewable energies.	*Consistency2_IM*
3rd level: consistency of the instrument mix with the policy strategy	The planned expansion target for renewable energies in Germany up to 2025 can be achieved with the help of existing policy instruments and measures.	*Consistency3_PM*
Credibility	Concerning the increase of electricity generation from renewable energies in Germany, there is …	
Policy mix credibility at national level	...a broad consensus across all political parties	*Credibility_national*
	...a clear political vision	
	...a firm political will	
	...unambiguous political signals	
	...strong support from the German government	
Policy mix credibility at sub-national level	...strong support from Federal States	*Credibility_subnational*
	...strong support from municipalities	
Coherence		
Informational coherence	There is a continuous exchange of information between policymakers and manufacturers.	*Coherence_informational*
	Policymakers are well informed about developments in the branch.	
	Emerging problems are spotted early on by policymakers.	
	Policymakers always strive to remove obstacles.	
	The search for solutions to problems takes place in a constructive exchange between policymakers and representatives of the RE branch.	
Procedural coherence	The last amendments of the EEG (2012 and today) were made in a transparent procedure.	*Coherence_procedural*
	The responsibilities for the branch are clearly regulated in the relevant Federal ministries.	
	National and Federal State governments are pulling in the same direction.	
Comprehensiveness	Important flanking policy regulations are missing that push the expansion of renewables (e.g. on power market design or for grid expansion)	*Comprehensiveness*

Our explanatory variables for firm-internal factors include *size*, which is measured by the total sales of the firm in 2013 in domestic and foreign markets (i.e. for diversified firms this includes business fields other than the main renewable energy technology), and *experience*, which is measured as the number of years the firm had been offering products for the main renewable power generation technology (measured against 2014). The final explanatory variable *wind* takes on the value of one if the firm's responses referred to either onshore or offshore wind, and zero otherwise.[14] Table 3 shows the descriptive statistics of the variables used in the econometric analysis.

Table 3: Descriptive statistics of dependent and explanatory variables

Variables	Unit	Number of observations	Mean	Standard deviation	Minimum	Maximum
*Innovation expenditures 2014**	in 1,000 Euros	315	2,023	15,600	0	250,000
*Innovation expenditures 2015**	in 1,000 Euros	244	1,587	7,958	0	75,000
DemandPull	dummy	376	0.40	0.49	0	1
*TechPush**	in 1,000 Euros	387	46,600	245,000	0	2,000,000
Consistency1_PS	dummy	375	0.73	0.45	0	1
Consistency2_IM	dummy	380	0.72	0.45	0	1
Consistency3_PM	dummy	382	0.68	0.47	0	1
Credibility_national	score	387	0.75	0.33	0	1
Credibility_subnational	score	369	0.70	0.38	0	1
Coherence_informational	score	385	0.70	0.34	0	1
Coherence_procedural	score	384	0.64	0.36	0	1
Comprehensiveness	dummy	384	0.69	0.46	0	1
*Size (sales)**	in 1,000 Euros	314	239,000	901,000	0	10,000,000
*Experience**	years	380	14.11	11.36	0	64
Wind	dummy	387	0.24	0.43	0	1

* The natural logarithm is used in the econometric estimation.

5 Results

Our econometric analysis involves estimating several model specifications, reflecting the propositions derived in section 2. The results appear in Table 4. Heteroskedasticity-robust p-values are shown in parentheses below the parameter estimates. For lack of

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14 Including dummies for other renewable technologies produced coefficients which were far from statistical significance. To save degrees of freedom, we only incorporated *wind*.

degrees of freedom we do not start with a model which includes all explanatory variables in the same specification.

5.1 Base model

As a first step, we estimated a *base model*, which includes *DemandPull, TechPush*, and *Controls* as explanatory variables, thus abstracting from any policy mix characteristics. Table 4 presents the results of this base model in the first set of columns. We find that the correlation is positive between the two equations (ρ = 0.918), and statistically significant. [15] .

In general, all coefficients in the base model exhibit the expected signs and are statistically significant. [16] In particular, the findings confirm the positive relation of global demand pull and European technology push effects with innovation expenditures in 2014 and 2015. [17] The point estimate of 0.29 for the coefficient of *TechPush* in the R&D 2014 equation implies that on average an increase by one percent in public subsidies for R&D received for a manufacturer's main renewable power generation technology between 2011 and 2013, increases firm-level innovation expenditure in the subsequent year 2014 by 0.29 percent.

Larger firms (in terms of sales) and more experienced firms (in terms of years active in the main renewable power generation technology) are related with higher innovation expenditures in 2014 and 2015. For example, a one percent increase in sales or technology experience is associated with an increase in inovation expenditure in 2014 by 0.64 percent and 1.1 percent, respectively. Finally, firms active in wind technologies are associated with about 2.8 times higher innovation expenditures in 2014 compared to firms focusing on other renewable electricity technologies, indicating strong differences across technologies.

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15 Based on a Likelihood-Ratio test, the Null Hypothesis (ρ = 0) can be rejected at $p<0.01$ ($\chi^2(1) = 320.061$).

16 We calculated variance inflation factors (VIF) to explore whether collinearity may be a problem. Using all explanatory variables employed in this and subsequent specifications, the average VIF is 1.33. The highest VIF of any explanatory variable is 2.30 for *credibility_nationa*l. Thus, our parameter estimates do not appear to suffer from collinearity.

17 We ran an additional base model allowing *TechPush* and *DemandPull* to interact. While the coefficient of this interaction term took on the expected positive sign, the p-values were quite high (0.60 and 0.72). Otherwise, the findings were virtually the same as those of the base model, but the AIC and BIC values were noticeably higher, i.e. 2025 for AIC and 2082 for BIC.

Next, we employ several models to test the effects of policy mix characteristics on innovation expenditures. We first note that for these models the coefficients of the variables included in the base model are very similar to those of the base model, i.e. they are barely affected by including the additional policy mix variables; however, the model quality tends to improve, as indicated by smaller AIC and BIC values.

5.2 Consistency models

We start by testing the effects of *consistency* of the policy mix on innovation expenditures. To do so we first extend the base model to include our variables for the three levels of consistency individually, and then combined. The estimation results for the individual models suggest that *Consistency1_PS (*consistency of the policy strategy) exhibits the expected positive sign but is not statistically significant, leading us to reject proposition 1.1. In comparison, the coefficients for *Consistency2_IM* (consistency of the instrument mix) and *Consistency3_PM* (consistency of the instrument mix with the policy strategy, i.e. the overarching policy mix) are, as expected, positive in both equations, and are also statistically significant – except for the 2014 innovation expenditure equation, where *Consistency_level2* is only significant at p<0.142 (i.e. at a significance level which slightly exceeds conventional levels). However, when the variables for all three consistency levels are included simultaneously, only *Consistency3_PM* turns out to be statistically significant, and only for innovation expenditures in 2015 (for 2014 *Consistency3_PM* becomes significant at p<0.142). Most likely, this loss in significance is due to the loss in degrees of freedom. In summary, these findings provide weak support for proposition 1.2 and fairly strong support for proposition 1.3.

5.3 Credibility models

To explore the impact of the *credibility* of the policy mix on innovation expenditures we included our two indicators derived from the factor analysis in the base model. *We find Credibility_national* (policy mix credibility at national level) to be positively related to innovation expenditures and also statistically significant in both equations. In contrast, innovation expenditures do not appear to be related with *Credibility_subnational* (policy mix credibility at sub-national level). Thus, our results support proposition 2, albeit only at a national level.

In addition, we allowed for a possible interaction of consistency and credibility. More specifically, we included an interaction term for third level consistency of the overarching policy mix (i.e. the consistency between instrument mix and policy strategy) and national credibility (*Cons3 X Cred_nat*) together with *Consistency3_PM* and *Credibility_national.* The interaction term turns out to be negative and statistically significant for innovation expenditures in 2015 (for 2014, p = 0.129, hence just above conventional levels). At the same time, the coefficients for *Consistency3_PM* and *Credibility_national* remain positive and exhibit lower p-values for innovation expenditures in 2014 and in 2015 than in the model without such interaction. Thus, an increase in *Credibility_national* is associated with a larger positive effect on R&D if *consistency3_PM* is low. Likewise, an increase in *Consistency3_PM* is associated with a larger positive effect on innovation expenditures if *Credibility_national* is low.[18] This confirms our third proposition.

5.4 Coherence model

In our model capturing the *coherence* of policy processes the coefficients of the indicators capturing informational and procedural coherence both exhibit the expected positive sign for innovation expenditures in 2014 and 2015. However, the coefficients are not statistically significant. We therefore reject proposition 4.

5.5 Comprehensiveness model

Similarly, our model addressing the comprehensiveness of the instrument mix shows that the coefficient of *comprehensiveness* is positive for innovation expenditures in 2014 and 2015, but lacks statistical significance, leading us to reject proposition 5.

5.6 Overall model

Finally, we estimate the full model which includes all explanatory variables. The results are very similar to those for the individual models, but significance levels for the coefficients tend to be inferior, most likely due to lack of power. In particular, unlike in the individual model, *Credibility_national* is no longer statistically significant at conventional levels, yet the p-value is quite low (p = 0.128). In general though, the findings of the full model and the individual models are very consistent, suggesting that a potential omitted variable bias is negligible. In summary, the findings of the overall model, which has the lowest AIC and BIC values of all examined models, provide solid support for propositions 1.3 and 3, and offer weak support for proposition 2.

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18 In a separate model, we also allowed *Consistency2_IM* (i.e. the consistency of the instrument mix) and *Credibility_national* to interact. The coefficient was negative in both equations, but not statistically significant (p-values > 0.2 in both equations).

Table 4: Regression results for base model and nine models including policy mix characteristics

	Base model		*Consistency1_PS*		*Consistency2_IM*		*Consistency3_PM*		*Consistency_all*		*Credibility*		*Cons3 X Cred_nat*		*Coherence*		*Comprehensiveness*		*Full model*	
Variable	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
DemandPull	**2.399*** **	**4.396*** **	**2.305*** **	**4.331*** **	**2.438*** **	**4.318*** **	**2.152** **	**4.025*** **	**2.287*** **	**4.165*** **	**2.550*** **	**4.524*** **	**2.106** **	**4.090*** **	**2.228** **	**4.115*** **	**2.431*** **	**4.429*** **	**3.040*** **	**4.971*** **
	(0.006)	**(0.000)**	**(0.010)**	**(0.000)**	**(0.006)**	**(0.000)**	**(0.012)**	**(0.000)**	**(0.010)**	**(0.000)**	**(0.007)**	**(0.000)**	**(0.019)**	**(0.000)**	**(0.015)**	**(0.000)**	**(0.005)**	**(0.000)**	**(0.002)**	**(0.000)**
TechPush	**0.290*** **	**0.270** **	**0.303*** **	**0.283*** **	**0.309*** **	**0.306*** **	**0.273*** **	**0.238** **	**0.288*** **	**0.263** **	**0.300*** **	**0.327*** **	**0.298*** **	**0.270*** **	**0.292*** **	**0.271** **	**0.286*** **	**0.259** **	**0.268*** **	**0.272** **
	(0.002)	**(0.012)**	**(0.001)**	**(0.009)**	**(0.002)**	**(0.008)**	**(0.002)**	**(0.019)**	**(0.004)**	**(0.020)**	**(0.001)**	**(0.005)**	**(0.001)**	**(0.009)**	**(0.002)**	**(0.011)**	**(0.002)**	**(0.014)**	**(0.009)**	**(0.034)**
Size	**0.637*** **	**0.693*** **	**0.616*** **	**0.672*** **	**0.640*** **	**0.678*** **	**0.615*** **	**0.647*** **	**0.628*** **	**0.659*** **	**0.604*** **	**0.738*** **	**0.624*** **	**0.664*** **	**0.607*** **	**0.644*** **	**0.636*** **	**0.694*** **	**0.642*** **	**0.731*** **
	(0.001)	**(0.002)**	**(0.001)**	**(0.002)**	**(0.001)**	**(0.003)**	**(0.001)**	**(0.002)**	**(0.001)**	**(0.002)**	**(0.001)**	**(0.002)**	**(0.001)**	**(0.001)**	**(0.001)**	**(0.003)**	**(0.001)**	**(0.002)**	**(0.001)**	**(0.003)**
Experience	**1.088***	**1.347***	**1.044***	**1.298***	**1.030***	**1.305***	**1.179** **	**1.513** **	**1.044***	**1.385** **	**1.024***	**1.600** **	**1.065***	**1.362** **	**1.294** **	**1.625** **	**1.099***	**1.382** **	**1.008***	**1.803** **
	(0.065)	**(0.053)**	**(0.081)**	**(0.067)**	**(0.077)**	**(0.054)**	**(0.045)**	**(0.026)**	**(0.075)**	**(0.041)**	**(0.086)**	**(0.040)**	**(0.066)**	**(0.038)**	**(0.028)**	**(0.016)**	**(0.063)**	**(0.046)**	**(0.096)**	**(0.017)**
Wind	**2.804*** **	**2.306** **	**2.686*** **	**2.196***	**2.356** **	1.647	**2.172** **	1.310	**1.962** **	1.065	**2.039** **	1.652	**2.094** **	1.233	**2.752*** **	**2.243***	**2.797*** **	**2.277** **	**1.839***	1.140
	(0.003)	**(0.045)**	**(0.005)**	**(0.066)**	**(0.012)**	(0.147)	**(0.019)**	(0.234)	**(0.038)**	(0.345)	**(0.038)**	(0.203)	**(0.023)**	(0.262)	**(0.004)**	**(0.055)**	**(0.003)**	**(0.047)**	**(0.071)**	(0.391)
Consistency1_PS			0.974	0.967					0.377	-0.039									-0.166	-0.795
			(0.373)	(0.455)					(0.728)	(0.975)									(0.883)	(0.586)
Consistency2_IM					1.664	**2.745** **			0.731	1.460									-0.522	0.878
					(0.142)	**(0.046)**			(0.568)	(0.338)									(0.714)	(0.633)
Consistency3_PM							**2.119***	**3.618*** **	1.790	**3.103** **			**4.669** **	**8.305*** **					**4.691***	**8.179** **
							(0.053)	**(0.006)**	(0.142)	**(0.032)**			**(0.049)**	**(0.004)**					**(0.079)**	**(0.022)**
Credibility_national											**2.611***	**3.832***	**4.706***	**7.015** **					5.005	5.253
											(0.098)	**(0.070)**	**(0.078)**	**(0.032)**					(0.128)	(0.233)
Credibility_subnational											1.247	1.716							0.677	0.488
											(0.345)	(0.327)							(0.621)	(0.787)
Cons3 X Cred_nat													-4.797	**-8.105** **					-5.540	**-7.942***
													(0.129)	**(0.033)**					(0.111)	**(0.087)**
Coherence_informational															0.987	1.609			-0.639	0.395
															(0.556)	(0.419)			(0.755)	(0.881)
Coherence_procedural															1.838	2.599			1.984	2.735
															(0.268)	(0.193)			(0.312)	(0.285)
Comprehensiveness																	0.434	1.168	0.293	0.942
																	(0.667)	(0.342)	(0.789)	(0.518)
Constant	**-7.428** **	**-10.637** **	**-7.697** **	**-10.913*** **	**-8.429** **	**-12.070*** **	**-8.369** **	**-12.220*** **	**-8.860** **	**-12.813*** **	**-9.472** **	**-16.710*** **	**-10.734*** **	**-15.986*** **	**-9.309*** **	**-13.281*** **	**-7.745** **	**-11.523*** **	**-12.041*** **	**-21.018*** **
	(0.033)	**(0.012)**	**(0.025)**	**(0.009)**	**(0.020)**	**(0.005)**	**(0.013)**	**(0.002)**	**(0.011)**	**(0.002)**	**(0.010)**	**(0.001)**	**(0.004)**	**(0.000)**	**(0.007)**	**(0.001)**	**(0.030)**	**(0.007)**	**(0.003)**	**(0.000)**
(Pseudo)loglikelihood (Chi-Squared)	-995.691 (63.85***)		-975.705 (63.67)		-985.113 (72.11)		-988.341 (78.95)		-960.156 (82.24)		-921.181 (69.89)		-984.231 (84.87)		-981.870 (72.61)		-994.63696 (65.93)		-873.423 (93.72)	
Rho (Chi-Squared)	0.918 (320.061***)		0.918 (312.664***)		0.915 (309.794***)		0.917 (313.363***)		0.915 (299.624***)		0.938 (329.754 ***)		0.917 (311.903 ***)		0.916 (311.193)		0.918 (320.867)		0.942 (319.397)	
AIC	2021,382		1985,411		2004,227		2010,681		1962,310		1880,363		2010,462		2001,741		2023,274		1812,846	
BIC	2071,942		2042,392		2061,369		2067,903		2032,398		1943,407		2081,147		2065,605		2080,575		1921,024	
Observations	215		211		213		214		208		204		214		213		215		196	

Legend: PS=policy strategy, IM=instrument mix, PM=policy mix, Cons3= third level consistency, Cred_nat=credibility at national level; Robust pval in parentheses, *** p<0.01, ** p<0.05, * p<0.1

6 Discussion

Keeping in mind the explorative character of our study we find evidence that for the case of renewable power generation technologies in Germany policy mix characteristics matter for innovation. In particular, by incorporating a distinct block of questions on companies' perceptions of the current policy mix our econometric analysis suggests a positive link between the *consistency* and *credibility* of the policy mix and corporate innovation expenditures on low carbon innovation. In our case, this finding implies that technology providers which consider the instrument mix to be fairly well aligned with the expansion targets for renewable electricity and which perceive a high level of governmental commitment spend more on low carbon innovation. Perhaps most strikingly, we find a negative interaction effect between the consistency of the overall policy mix and policy mix credibility at a national level, indicating that both characteristics influence each other. The effect of policy mix credibility on innovation expenditures is larger when policy mix consistency is low. Similarly, the effect of consistency of the policy mix on innovation expenditures is larger when credibility is low. This finding is in line with the results of qualitative case study work by Reichardt and Rogge (2016) for offshore wind in Germany. Accordingly, inconsistencies in the policy mix were partly offset by a high level of credibility, thereby reducing negative impacts on innovation. This finding may also be reassuring to policy makers which may not be able to align at once the entire policy mix with novel green targets. For example, conflicting policy objectives or political resistance from incumbent, more polluting companies may slow down the necessary changes. Indeed, such inconsistencies may be partly unavoidable and inherent to sustainability transitions (Quitzow, 2015a; Rogge and Reichardt, 2016), but their detrimental impact on green innovation may be reduced if innovators perceive a strong political commitment and thus high policy mix credibility.

In contrast, our study does not support earlier findings on a positive effect of instrument mix *comprehensiveness* on innovation (Costantini et al., 2017). This may be explained, for example, by differences in technologies (energy efficiency versus renewable technologies), indicators of innovation (patents versus innovation expenditures), estimation methodology (panel versus cross-section analysis), regional scope (OECD countries versus Germany) or data sources (secondary versus primary data from survey). However, it could also be that comprehensiveness may be more important for adoption of renewable energies, and less for innovation decisions (Sovacool, 2009; Reichardt and Rogge, 2016).

Regarding the *coherence* of policy processes as the fourth policy mix characteristic included in our study, we do not find sufficient evidence for a direct link with innovation.

However, it is noteworthy that respondents were well able to answer our various items on the coherence of policy making and implementation, and that based on their answers we arrived at two distinct factors capturing procedural and informational coherence. Also, the relatively low p-value for procedural coherence indicates that it may be worthwhile to investigate this phenomenon further. This is also backed up by qualitative work which has shown a clear impact of the policy making style on green innovation, at least for the case of offshore wind in Germany (Reichardt et al., 2017). We argue that studies with a larger sample size can be expected to shed more light on the relationship between the coherence of policy processes and innovation (and other policy mix characteristics, for that matter). Similarly, studies involving several countries could not only improve statistical power, but also exploit variation across countries. Of course, an alternative explanation for our results may be the potential omission of key items needed to capture policy mix coherence. Finally, it could also be the case that coherence rather unfolds its role for innovation more indirectly, for example by influencing the credibility of a policy mix.

Turning to *technology push* instruments we find that public financial support for innovation projects is linked with higher private innovation expenditures in the future. This is in line with the literature finding that public R&D support stimulates green innovation, albeit with some variation across technologies (Johnstone et al., 2010; Costantini et al., 2015). Yet, perhaps more importantly, our study adds to existing evidence suggesting that the locus of public technology push funding matters, but qualifies this for Europe where companies have access to both national and EU R&D funding which jointly matter.

Regarding *demand pull* effects our study supports earlier findings that market growth – which in the case of renewable energies at the time of our survey has still mainly been policy-induced – is positively associated with green innovation (Horbach, 2008; Hoppmann et al., 2013; Schleich et al., 2017). In our case, technology providers who expect their green sales to increase compared to the previous year tend to spend more on low-carbon innovation. Of course, this growth expectation measured at the firm-level rather than through national or global capacity additions is not only dependent on policy-induced market growth but also on the international competiveness of firms, where, for example, in the case of solar PV German companies have been particularly challenged by Chinese competitors (Quitzow, 2015b). To sum up, global market expectations matter which in the case of green innovation are driven by policy mixes, with demand pull instruments as well as targets playing a key role (Rogge et al., 2011; Schmidt et al., 2012b).

In terms of our *control variables* we find strong support for *size* of the firm (measured in total sales in 2013) positively impacting on low carbon innovation expenditures. This result is in line with the eco-innovation literature (Kammerer, 2009; Kesidou and Demirel, 2012; del Río et al., 2016). In addition, we also find evidence that *experience* with the main renewable power generation technology (measured in years) positively correlates with green innovation expenditures, suggesting that early movers spend more on innovation. This underlines the importance of green technological and organizational capabilities found in the eco-innovation literature (Kammerer, 2009; Demirel and Kesidou, 2011; Horbach et al., 2012). Finally, regarding the technology portfolio our findings hint at possible differences across technologies (Huenteler et al., 2016), with companies active in on- and offshore wind having higher innovation expenditures than the rest. Finally, the high significance of our error term hints at path dependency of green innovation expenditures between 2014 and 2015, although this correlation may also be due to factors other than green innovation breeding green innovation (Horbach, 2008).

Overall, we argue that our explorative study provides empirical support for drawing on the broader policy mix concept introduced by Rogge and Reichardt (2016). In particular, we find strong evidence for a positive relation between innovation expenditures in renewable power technologies and the overall consistency of the policy mix, i.e. how well aligned the instrument mix is with policy targets. Our findings also suggest that policy mix credibility plays a key role, although the mechanisms through which credibility – and in particular its link with consistency – matters for innovation remain to be better understood.

7 Conclusion

In this paper we presented new insights on the link between policy and innovation. More specifically, operationalizing policy mix consistency, comprehensiveness, credibility and coherence in an innovation survey enabled us to perform the first survey-based quantitative analysis on the relevance of these policy mix characteristics for green innovation. Our findings for the research case of manufacturers of renewable power generation technologies in Germany suggest that policy mix consistency and credibility matter for innovation, and that this positive link intensifies when considering their mutual interdependence. In addition, our findings point to the potential relevance of the procedural coherence of policy processes, but do not support earlier claims that the comprehensiveness of the instrument mix is key for innovation. These findings also speak to innovation studies more broadly, confirming the relevance of paying greater attention to policy mixes (Guerzoni and Raiteri, 2015; Cantner et al., 2016) but suggesting a broader scope of future policy mix research.

Clearly, our novel empirical research is not free from limitations. Rather, it should be seen as a first step in analyzing the impact of policy mix characteristics on green innovation. First, for such an exploratory study choosing the German *Energiewende* allows drawing lessons from one of the most advanced cases of a low-carbon transition, but the focus on one country and one sector implies that our results may not readily be transferable to other contexts. Second, while operationalizing policy mix characteristics proved feasible within an innovation survey, and the correlations found between R&D and the policy mix variables build upon and support earlier qualitative findings, we also recognize the caveats inherent with survey-based research such as recall-bias, social desirability bias or common method bias. In addition, to establish causality, panel data would be preferable. Third, our operationalizations for the measurement of perceptions on the policy mix should only be seen as first attempt. For example, future studies can include strong instrument mix consistency characterized by the existence of synergies between different instruments rather than just capturing the absence of contradictions, or could test multiple alternative items for comprehensivenes. Also, future work can cover more than just energy and climate policy strategies, and therefore examine consistency between environmental and other policy objectives, such as competitiveness or distributional concerns. Similarly, based on our in-depth study for the German policy mix future analysis should extend the scope, so as to include, for example, the Paris Climate Agreement or EU climate and renewable energy targets since such international long-term targets may also influence innovation strategies (Schmidt et al., 2012b; Schleich et al., 2017). In light of the increasingly global nature of the market for renewable power generation technologies studying the differential effects of domestic and global policy mix characteristics seems also promising.

Despite these caveats we argue that our findings do not only hold relevant implications for German policy makers but also provide important indications for transformative innovation policy more generally (Schot and Steinmueller, 2016). First, our results suggest that policy makers interested in stimulating green innovation are well advised to think more holistically in terms of the consistency of the *overarching* policy mix, that is, striving for instrument mixes which are mutually supportive and well aligned with long-term targets. Second, since policy mix *credibility* seems to stimulate green innovation, policy makers need to recognize this importance and better understand the formation (and loss) of such credibility. Third, our study provides some indications that policy makers interested in redirecting and accelerating innovation towards green solutions should pay greater attention to the *coherence* of policy processes. This concerns, for example, policy makers problem solving capabilities and the mode of interaction with innovators. Finally, the decarbonization of the economy requires dedicated efforts to better monitor the greening of innovation and drivers thereof. For example, standard monitoring tools, such as the Community Innovation Survey, should be adjusted to provide a better base for evidencing the role of policy mixes for the steering of such a transition.

Based on the results of our exploratory study we foresee three main areas for future research, all intended to deepen empirical insights into the innovation impact of policy mixes for sustainability transitions. First, conducting a periodic innovation survey among manufacturers of technologies relevant for the low-carbon energy transition may help in investigating the causality of policy mixes and innovation. Such a *panel* should not only include technology providers active in the field of renewable energy, but capture the ongoing system innovation more broadly, e.g. by also including complementary or enabling technologies, such as storage or grid technologies. Second, to better understand the relevance of the characteristics of policy mixes, such as consistency and credibility, *cross-country innovation surveys* should be conducted. For example, a comparative study of countries with a similar industry structure but different governance approaches regarding the transition of the energy system, such as the US, France, Japan or Italy, could enable important insights into the link between policy and low-carbon innovation. Finally, analyzing the relevance of policy mixes for green innovation should be extended beyond the energy domain to capture its role for the greening of the economy more generally. For example, the CIS or similar surveys could include policy mix questions to allow for *cross-sectoral comparisons*. If implemented in more than one country, this would also allow for cross-country comparisons. Ultimately, our findings may initiate a critical assessment of how policy is measured in innovation surveys and beyond. Future research may help establishing new standards in innovation surveys, where items on policy are not limited to an optional eco-innovation module but where both policy mixes and green innovation are integrated more holistically.

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8 References

Ashoff, G., 2005. Enhancing Policy Coherence for Development: Justification, Recognition and Approaches to Achievement. DIE Studies 11. German Development Institute, Bonn.

Barney, J., 2001. Resource-based theories of competitive advantage: A ten-year retrospective on the resource-based view. Journal of Management 27 (6), 643–650. 10.1016/S0149-2063(01)00115-5.

Barslund, M.C., 2009. MVTOBIT: Stata module to calculate mulitvariate tobit models by simulated maximum likelihood (SML). http://EconPapers.repec.org/RePEc:boc:bocode:s456875.

Bergek, A., Berggren, C., 2014. The impact of environmental policy instruments on innovation: A review of energy and automotive industry studies. Ecological Economics 106, 112–123. 10.1016/j.ecolecon.2014.07.016.

BMWi, 2014. Act on the Development of Renewable Energy Sources (Renewable Energy Sources Act - RES Act 2014): EEG.

BMWi, 2015. The Energy of the Future - Fourth "Energy Transition" Monitoring Report - Summary: A good piece of work. Federal Ministry for Economic Affairs and Energy, Berlin.

BMWi, 2016a. 10-point agenda: A clear roadmap for the energy transition. Federal Ministry for Economic Affairs and Energy. http://www.bmwi.de/Redaktion/EN/Dossier/energy-transition.html. Accessed 27 June 2017.

BMWi, 2016b. Bundesbericht Energieforschung 2016: Forschungsförderung für die Energiewende. Federal Ministry for Economic Affairs and Energy, Berlin.

BMWi, BMU, 2010. Energy Concept for an Environmentally Sound, Reliable and Affordable Energy Supply. Federal Ministry of Economics and Technology, Federal Ministry for the Environment, Berlin.

Borghesi, S., Cainelli, G., Mazzanti, M., 2015. Linking emission trading to environmental innovation: Evidence from the Italian manufacturing industry. Research Policy 44 (3), 669–683. 10.1016/j.respol.2014.10.014.

Bosetti, V., Victor, D.G., 2011. Politics and Economics of Second-Best Regulation of Greenhouse Gases: The Importance of Regulatory Credibility. The Energy Journal 32 (1), 1–24.

Bouckaert, G., Peters, B.G., Verhoest, K., 2010. The Coordination of Public Sector Organizations, Shifting Patterns of Public Management. Palgrave Macmillan, Basingstoke.

Bruns, E., Ohlhorst, D., Wenzel, B., Köppel, J., 2011. Renewable Energies in Germany's Electricity Market. Springer Netherlands, Dordrecht.

Cai, W.-g., Zhou, X.-l., 2014. On the drivers of eco-innovation: Empirical evidence from China. Journal of Cleaner Production 79, 239–248. 10.1016/j.jclepro.2014.05.035.

Cantner, U., Graf, H., Herrmann, J., Kalthaus, M., 2016. Inventor networks in renewable energies: The influence of the policy mix in Germany. Research Policy 45 (6), 1165–1184. 10.1016/j.respol.2016.03.005.

Cefis, E., Orsenigo, L., 2001. The persistence of innovative activities: A cross-countries and cross-sectors comparative analysis. Research Policy 30, 1139–1158.

Costantini, V., Crespi, F., Martini, C., Pennacchio, L., 2015. Demand-pull and technology-push public support for eco-innovation: The case of the biofuels sector. Research Policy 44 (3), 577–595. 10.1016/j.respol.2014.12.011.

Costantini, V., Crespi, F., Palma, A., 2017. Characterizing the policy mix and its impact on eco-innovation: A patent analysis of energy-efficient technologies. Research Policy 46 (4), 799–819. 10.1016/j.respol.2017.02.004.

Dechezleprêtre, A., Glachant, M., 2014. Does Foreign Environmental Policy Influence Domestic Innovation?: Evidence from the Wind Industry. Environ Resource Econ 58 (3), 391–413. 10.1007/s10640-013-9705-4.

del Río, P., Carrillo-Hermosilla, J., Könnölä, T., Bleda, M., 2015. Resources, capabilities and competences for eco-innovation. Technological and Economic Development of Economy 22 (2), 274–292. 10.3846/20294913.2015.1070301.

del Río, P., Peñasco, C., Romero-Jordán, D., 2016. What drives eco-innovators?: A critical review of the empirical literature based on econometric methods. Journal of Cleaner Production 112, 2158–2170. 10.1016/j.jclepro.2015.09.009.

del Río González, Pablo, 2009. The empirical analysis of the determinants for environmental technological change: A research agenda. Ecological Economics 68 (3), 861–878. 10.1016/j.ecolecon.2008.07.004.

Demirel, P., Kesidou, E., 2011. Stimulating different types of eco-innovation in the UK: Government policies and firm motivations. Ecological Economics 70 (8), 1546–1557. 10.1016/j.ecolecon.2011.03.019.

Den Hertog, L., Stroß, S., 2011. Policy Coherence in the EU System: Concepts and Legal Rooting of an Ambiguous Term. Conference Paper "The EU as global player", Madrid.

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. 10.1016/j.respol.2012.03.021.

Diaz Anadon, L., Bunn, M., Narayanamurti, V. (Eds.), 2014. Transforming U.S. Energy Innovation. Cambridge University Press, New York.

Díaz-García, C., González-Moreno, Á., Sáez-Martínez, F.J., 2015. Eco-innovation: Insights from a literature review. Innovation: Management, Policy & Practice 17 (1), 6–23. 10.1080/14479338.2015.1011060.

Doblinger, C., Dowling, M., Helm, R., 2015. An institutional perspective of public policy and network effects in the renewable energy industry: Enablers or disablers of entrepreneurial behaviour and innovation? Entrepreneurship & Regional Development 28 (1-2), 126–156. 10.1080/08985626.2015.1109004.

Flanagan, K., Uyarra, E., Laranja, M., 2011. Reconceptualising the ‘policy mix’ for innovation. Research Policy 40 (5), 702–713. 10.1016/j.respol.2011.02.005.

Frondel, M., Horbach, J., Rennings, K., 2008. What triggers environmental management and innovation? Empirical evidence for Germany. Ecological Economics 66 (1), 153–160. 10.1016/j.ecolecon.2007.08.016.

Gallagher, K.S., Grübler, A., Kuhl, L., Nemet, G., Wilson, C., 2012. The Energy Technology Innovation System. Annu. Rev. Environ. Resour. 37 (1), 137–162. 10.1146/annurev-environ-060311-133915.

Gawel, E., Strunz, S., Lehmann, P., 2013. Germany's Energy Transition Under Attack: Is There an Inscrutable German *Sonderweg* ? Nat Cult 8 (2), 121–133. 10.3167/nc.2013.080201.

Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Neukirch, M., Wassermann, S., 2016. The enactment of socio-technical transition pathways: A re-formulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). Research Policy 45 (4), 896–913. 10.1016/j.respol.2016.01.015.

Ghisetti, C., Pontoni, F., 2015. Investigating policy and R&D effects on environmental innovation: A meta-analysis. Ecological Economics 118, 57–66. 10.1016/j.ecolecon.2015.07.009.

Grau, T., 2014. Responsive feed-in tariff adjustment to dynamic technology development. Energy Economics 44, 36–46. 10.1016/j.eneco.2014.03.015.

Greene, W.H., 2012. Econometric analysis. Pearson, Boston, London.

Guerría, A., 2016. From negotiations to implementation: strengthening global responses to climate change, in: UNFCCC (Ed.), G7 Climate Change: The New Economy. World News - CLIMATE CHANGE The New Economy, London, pp. 34–37.

Guerzoni, M., Raiteri, E., 2015. Demand-side vs. supply-side technology policies: Hidden treatment and new empirical evidence on the policy mix. Research Policy 44 (3), 726–747. 10.1016/j.respol.2014.10.009.

Helfat, C.E., Finkelstein, S., Mitchell, W., Peteraf, M.A., Singh, H., 2007. Dynamic capabilities: Understanding strategic change in organizations. Blackwell Publications, Oxford, Cambridge.

Helm, D., 2003. Credible Carbon Policy. Oxford Review of Economic Policy 19 (3), 438–450. 10.1093/oxrep/19.3.438.

Hermwille, L., 2016. The role of narratives in socio-technical transitions—Fukushima and the energy regimes of Japan, Germany, and the United Kingdom. Energy Research & Social Science 11, 237–246. 10.1016/j.erss.2015.11.001.

Hoppmann, J., Huenteler, J., Girod, B., 2014. Compulsive policy-making—The evolution of the German feed-in tariff system for solar photovoltaic power. Research Policy 43 (8), 1422–1441. 10.1016/j.respol.2014.01.014.

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. 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. 10.1016/j.respol.2007.08.006.

Horbach, J., Oltra, V., Belin, J., 2013. Determinants and Specificities of Eco-Innovations Compared to Other Innovations—An Econometric Analysis for the French and German Industry Based on the Community Innovation Survey. Industry and Innovation 20 (6), 523–543. 10.1080/13662716.2013.833375.

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. 10.1016/j.ecolecon.2012.04.005.

Howlett, M., Rayner, J., 2013. Patching vs Packaging in Policy Formulation: Assessing Policy Portfolio Design. Politics and Governance 1 (2), 170–182. 10.12924/pag2013.01020170.

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

IEA, IRENA, 2017. Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System. International Energy Agency; International Renewable Energy Agency, Paris, Bonn.

IRENA, 2013. Renewable Energy Innovation Policy: Success Criteria and Strategies. International Renewable Energy Agency, Bonn.

Jacobsson, S., Bergek, A., 2004. Transforming the energy sector: The evolution of technological systems in renewable energy technology. Industrial and Corporate Change 13 (5), 815–849. 10.1093/icc/dth032.

Jacobsson, S., Bergek, A., 2011. Innovation system analyses and sustainability transitions: Contributions and suggestions for research. Environmental Innovation and Societal Transitions 1 (1), 41–57. 10.1016/j.eist.2011.04.006.

Jaffe, A.B., Newell, R.G., Stavins, R.N., 2002. Environmental policy and technological change. Environmental & Resource Economics 22 (1-2), 41–69.

Jänicke, M., Blazejczak, J., Edler, D., Hemmelskamp, J., 2000. Environmental Policy and Innovation: An International Comparison of Policy Frameworks and Innovation Effects, in: Hemmelskamp, J., Rennings, K., Leone, F. (Eds.), Innovation-Oriented

Environmental Regulation: Theoretical Approach and Empirical Analysis. Springer Verlag, Heidelberg, pp. 125–152.

Johnstone, N. (Ed.), 2007. Environmental Policy and Corporate Behaviour. Elgar; OECD, Cheltenham, Paris.

Johnstone, N., Haščič, I., Popp, D., 2010. Renewable Energy Policies and Technological Innovation: Evidence Based on Patent Counts. Environ Resource Econ 45 (1), 133–155. 10.1007/s10640-009-9309-1.

Kammerer, D., 2009. The effects of customer benefit and regulation on environmental product innovation. Ecological Economics 68 (8-9), 2285–2295. 10.1016/j.ecolecon.2009.02.016.

Kang, S.B., Létourneau, P., 2016. Investors' reaction to the government credibility problem: A real option analysis of emission permit policy risk. Energy Economics 54, 96–107. 10.1016/j.eneco.2015.11.023.

Kaplan, S., Tripsas, M., 2008. Thinking about technology: Applying a cognitive lens to technical change. Research Policy 37 (5), 790–805. 10.1016/j.respol.2008.02.002.

Kemp, R., Pearson, P., 2007. MEI D15 - Final report MEI project about measuring ecoinnovation: Deliverable 15. UM-MERIT, Maastricht.

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. 10.1016/j.ecolecon.2011.09.014.

Kern, F., Howlett, M., 2009. Implementing transition management as policy reforms: A case study of the Dutch energy sector. Policy Sci 42 (4), 391–408. 10.1007/s11077-009-9099-x.

Kesidou, E., Demirel, P., 2012. On the drivers of eco-innovations: Empirical evidence from the UK. Research Policy 41 (5), 862–870. 10.1016/j.respol.2012.01.005.

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. 10.1016/j.erss.2015.04.009.

Kuzemko, C., Mitchell, C., Lockwood, M., Hoggett, R., 2017. Policies, politics and demand side innovations: The untold story of Germany’s energy transition. Energy Research & Social Science 28, 58–67. 10.1016/j.erss.2017.03.013.

Lauber, V., Jacobsson, S., 2016. The politics and economics of constructing, contesting and restricting socio-political space for renewables – The German Renewable Energy Act. Environmental Innovation and Societal Transitions 18, 147–163. 10.1016/j.eist.2015.06.005.

Magro, E., Navarro, M., Zabala-Iturriagagoitia, J.M., 2014. Coordination-Mix: The Hidden Face of STI Policy. Review of Policy Research 31 (5), 367–389. 10.1111/ropr.12090.

Matthes, F.C., 2017. Energy transition in Germany: A case study on a policy-driven structural change of the energy system. Evolut Inst Econ Rev 14 (1), 141–169. 10.1007/s40844-016-0066-x.

Mazzucato, M., 2015a. From Market Fixing to Market Creating: A New Framework for Economic Policy. SPRU Working Paper Series (SWPS) 25, 23 pp.

Mazzucato, M., 2015b. The Green Entrepreneurial State. SPRU Working Paper Series (SWPS) 28. University of Sussex, Brighton.

Negro, S.O., Alkemade, F., Hekkert, M.P., 2012. Why does renewable energy diffuse so slowly?: A review of innovation system problems. Renewable and Sustainable Energy Reviews 16 (6), 3836–3846. 10.1016/j.rser.2012.03.043.

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

Nemet, G.F., Braden, P., Cubero, E., Rimal, B., 2014. Four decades of multiyear targets in energy policy: aspirations or credible commitments? WIREs Energy Environ 3 (5), 522–533. 10.1002/wene.116.

Nemet, G.F., Jakob, M., Steckel, J.C., Edenhofer, O., 2017. Addressing policy credibility problems for low-carbon investment. Global Environmental Change 42, 47–57. 10.1016/j.gloenvcha.2016.12.004.

Nooteboom, B., 2009. A Cognitive Theory of the Firm: Learning, Governance and Dynamic Capabilities. Edward Elgar Publishing, Cheltenham,UK.

OECD, 1996. Building Policy Coherence: Tools and Tensions. PUMA Public Management Occasional Papers 12, Paris.

OECD, 2001. The DAC Guidelines Poverty Reduction, Paris.

OECD, 2005. Oslo Manual: Guidelines for collecting and interpreting innovation data. 3rd edition, Paris.

OECD, 2009. Eco-Innovation in Industry - Enabling Green Growth, Paris.

OECD, 2011. Better Policies to Support Eco-innovation. OECD Studies on Environmental Innovation, Paris.

OECD, 2015. System Innovation: Synthesis Report, Paris.

OECD/IEA/NEA/ITF, 2015. Aligning Policies for a Low-carbon Economy. OECD, Paris, 242 pp.

Pavitt, K., 1984. Sectoral patterns of technical change: Towards a taxonomy and a theory. Research Policy 13 (6), 343–373. 10.1016/0048-7333(84)90018-0.

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. 10.1016/j.enpol.2014.06.031.

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. 10.1016/j.respol.2012.02.004.

Quitzow, L., Canzler, W., Grundmann, P., Leibenath, M., Moss, T., Rave, T., 2016. The German Energiewende – What's happening? Introducing the special issue. Utilities Policy 41, 163–171. 10.1016/j.jup.2016.03.002.

Quitzow, R., 2015a. Assessing policy strategies for the promotion of environmental technologies: A review of India's National Solar Mission. Research Policy 44 (1), 233–243. 10.1016/j.respol.2014.09.003.

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

Rammer, C., Schubert, T., Hünermund, P., Köhler, M., Iferd, Y., Peters, B., 2016. Dokumentation zur Innovationserhebung 2015. Dokumentation 16-01. ZEW, Mannheim.

Raymond, W., Mohnen, P., Palm, F., van der Schirm Loeff, S., 2010. Persistence of innovation in Dutch Manufacturing: is it spurious? The Review of Economics and Statistics 92 (3), 495–504.

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

Reichardt, K., Rogge, K., 2016. How the policy mix impacts innovation: Findings from company case studies on offshore wind in Germany. Environmental Innovation and Societal Transitions 18, 62–81. 10.1016/j.eist.2015.08.001.

Reichardt, K., Rogge, K.S., Negro, S.O., 2017. Unpacking policy processes for addressing systemic problems in technological innovation systems: The case of offshore wind in Germany. Renewable and Sustainable Energy Reviews 80, 1217–1226. 10.1016/j.rser.2017.05.280.

Rennings, K., 2000. Redefining innovation — eco-innovation research and the contribution from ecological economics. Ecological Economics 32 (2), 319–332. 10.1016/S0921-8009(99)00112-3.

Rennings, K., Rammer, C., 2011. The Impact of Regulation-Driven Environmental Innovation on Innovation Success and Firm Performance. Industry and Innovation 18 (3), 255–283. 10.1080/13662716.2011.561027.

Richter, M., 2013a. Business model innovation for sustainable energy: How German municipal utilities invest in offshore wind energy. International Journal of Technology Management 63 (1-2), 24–50.

Richter, M., 2013b. German utilities and distributed PV: How to overcome barriers to business model innovation. Renewable Energy 55, 456–466. 10.1016/j.renene.2012.12.052.

Rogge, K.S., Hoffmann, V.H., 2010. The impact of the EU ETS on the sectoral innovation system for power generation technologies. Energy Policy 38 (12), 7639–7652. 10.1016/j.enpol.2010.07.047.

Rogge, K.S., Reichardt, K., 2016. Policy mixes for sustainability transitions: An extended concept and framework for analysis. Research Policy 45 (8), 1620–1635. 10.1016/j.respol.2016.04.004.

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. 10.1016/j.ecolecon.2010.09.032.

Schleich, J., Walz, R., Ragwitz, M., 2017. Effects of policies on patenting in wind-power technologies. Energy Policy 108, 684–695. 10.1016/j.enpol.2017.06.043.

Schmid, E., Knopf, B., Pechan, A., 2016. Putting an energy system transformation into practice: The case of the German Energiewende. Energy Research & Social Science 11, 263–275. 10.1016/j.erss.2015.11.002.

Schmid, E., Pechan, A., Mehnert, M., Eisenack, K., 2017. Imagine all these futures: On heterogeneous preferences and mental models in the German energy transition. Energy Research & Social Science 27, 45–56. 10.1016/j.erss.2017.02.012.

Schmidt, T.S., Schneider, M., Hoffmann, V.H., 2012a. Decarbonising the power sector via technological change – differing contributions from heterogeneous firms. Energy Policy 43, 466–479. 10.1016/j.enpol.2012.01.041.

Schmidt, T.S., Schneider, M., Rogge, K.S., Schuetz, M.J.A., Hoffmann, V.H., 2012b. 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. 10.1016/j.eist.2011.12.002.

Schot, J., Steinmueller, E., 2016. Framing Innovation Policy for Transformative Change: Innovation Policy 3.0. University of Sussex, Brighton.

Smith Stegen, K., Seel, M., 2013. The winds of change: How wind firms assess Germany's energy transition. Energy Policy 61, 1481–1489. 10.1016/j.enpol.2013.06.130.

Smits, R., Kuhlmann, S., 2004. The rise of systemic instruments in innovation policy. IJFIP 1 (1/2), 4. 10.1504/IJFIP.2004.004621.

Sovacool, B.K., 2009. The importance of comprehensiveness in renewable electricity and energy-efficiency policy. Energy Policy 37 (4), 1–1529. 10.1016/j.enpol.2008.12.016.

Strunz, S., 2014. The German energy transition as a regime shift. Ecological Economics 100, 150–158. 10.1016/j.ecolecon.2014.01.019.

Taylor, M., 2008. Beyond technology-push and demand-pull: Lessons from California's solar policy. Energy Economics 30 (6), 2829–2854. 10.1016/j.eneco.2008.06.004.

Teece, D.J., Pisano, G., Shuen, A., 1997. Dynamic capabilities and strategic management. Strat. Mgmt. J. 18 (7), 509–533. 10.1002/(SICI)1097-0266(199708)18:7<509:AID-SMJ882>3.0.CO;2-Z.

Uyarra, E., Shapira, P., Harding, A., 2016. Low carbon innovation and enterprise growth in the UK: Challenges of a place-blind policy mix. Technological Forecasting & Social Change 103, 264–272. 10.1016/j.techfore.2015.10.008.

Veugelers, R., 2012. Which policy instruments to induce clean innovating? Research Policy 41 (10), 1770–1778. 10.1016/j.respol.2012.06.012.

Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive ‘failures’ framework. Research Policy 41 (6), 1037–1047. 10.1016/j.respol.2011.10.015.

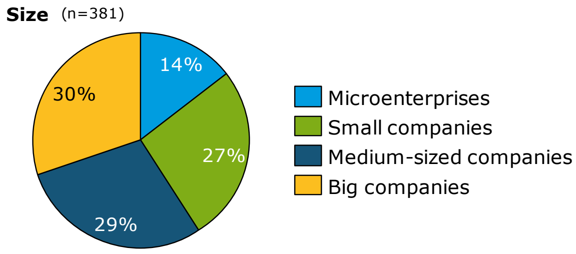
Wernerfelt, B., 1984. A Resource-Based View Of The Firm. Strateg.Manage.J. 5 (2), 171–180.

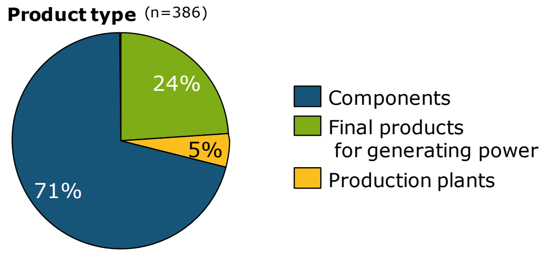
White, W., Lunnan, A., Nybakk, E., Kulisic, B., 2013. The role of governments in renewable energy: The importance of policy consistency. Biomass and Bioenergy 57, 97–105. 10.1016/j.biombioe.2012.12.035.

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. 10.1093/scipol/scr008.

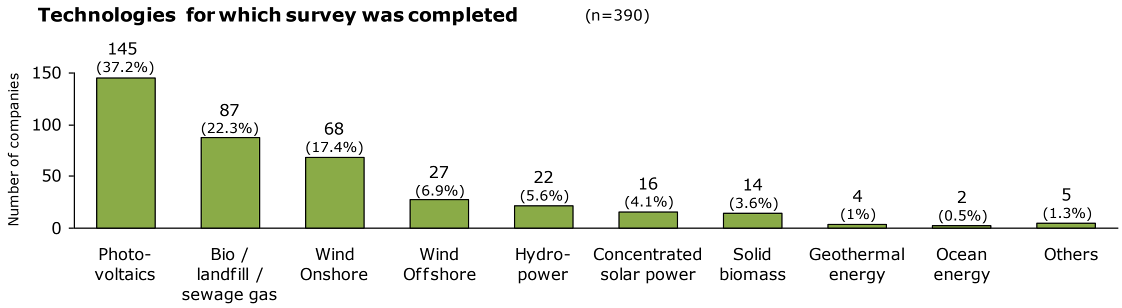
Ziegler, A., 2013. Disentangling technological innovations: A micro-econometric analysis of their determinants. Journal of Environmental Planning and Management 58 (2), 315–335. 10.1080/09640568.2013.855180.

Appendix A: Size and product type of participating companies





Appendix B: Technologies for which survey was completed



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