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Designing Policy Mixes for Sustainable Socio-technical Transitions

The Evolution and Effects of Policy Mixes for Low-Carbon Energy Transitions

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Abstract

There is an extensive body of literature analyzing the role of policy in inducing technological transitions, crossing the fields of economics, policy studies, and innovation studies. While innovation scholars have identified the important role of policy design features, economists, innovation scholars and policy scholars stress the importance of policy mixes. Thus far, the instrument design and the policy mix debates have been relatively de-coupled, leading to conceptual and empirical ambiguity. In this paper, we address this gap by conceptualizing the policy design features of *intensity* and *technology specificity* at the policy mix tier as well as proposing the policy mix characteristic *balance*. Intensity is a general policy design feature, whereas technology-specificity relates to technological transitions and the question to which extent policy makers should 'pick winners'. Policy mix balance measures the distribution of policies in a mix across different instrument types. We empirically apply these concepts to renewable energy policy mixes in nine OECD countries over seventeen years, analyzing 522 policies in total. We thereby address the following two research questions: First, how do renewable energy policy mixes differ between countries and over time regarding their design features intensity and technology-specificity as well as their balance? Second, to which extent can these differences explain observed variation in the diffusion of different renewable energy technologies? We detect strong variations in terms of policy mixes' intensity, technology-specificity, and balance between countries and over time. Regarding the effects of these variations on technology diffusion, we find that less mature and less regime-conform technologies require more technology-specific policy mixes. Adding policy mix balance to our model does not significantly improve its explanatory value. However, we find indications that balance plays an important role in the 'politics of policy mixes'. Based on these findings we discuss the contributions of our approach and implications for the next generation of policy mix studies.

Key words: Policy mixes; policy output assessment; policy effectiveness; sustainability transitions; low-carbon energy; index of policy activity (IPA)

1. Introduction

Mitigating climate change, ocean acidification, and other environmental issues related to carbon emissions requires a fast and substantial transition of the energy, transport and several industry sectors (IPCC 2011). Many countries have enacted policies that aim at accelerating and re-directing technological change, i.e., the invention, innovation and diffusion of new low-carbon technologies in these sectors. While some countries mostly rely on carbon pricing, others primarily focus on technology policies targeting low-carbon technologies, like renewable energy technologies (RET). The academic debate on policy outcomes has to large parts focused on the question which instrument types are most effective and efficient to induce an acceleration and re-direction of technological change (see e.g., Ashford 1993; Johnstone and Horbach 2005; del Río 2009; Rogge, Schneider, and Hoffmann 2011; Dong 2012; Schmidt et al. 2012). One of the key lessons learnt through comparative ex-post analysis of policy outcomes is that often the *design features* of a policy are (at least) as important as the instrument type (Ashford, Ayers, and Stone 1985; Kemp and Pontoglio 2011; Norberg-Bohm 1999; Yin and Powers 2010; Jenner et al. 2013). Despite this emerging consensus, however, the conceptualization and measurement of *general* policy design features remains heterogeneous, making it hard to relate empirical studies to each other. In addition, new policy design features that are particularly important for driving and shaping *technological change and transitions* are discussed, such as the *technology-specificity* of an instrument, i.e., whether a policy is technology neutral, targets a specific group of technologies, a specific technology, or even a sub-technologies (Azar and Sandén, 2011; Schmidt et al., 2016).

Besides these discussions on the instrument tier, research has begun to investigate policy instrument *mixes*, i.e. the in reality always present combination of policy instruments and their interplay (see e.g., Flanagan, Uyarra, and Laranja 2011; Howlett and del Rio 2015; Howlett 2014; Kern and Howlett 2009; Rogge and Reichardt 2016). This strand of literature stresses that focusing on individual instruments is too simplistic, as (i) many system failures are involved in technological change and transitions, which cannot be addressed by a single instrument (see e.g., Waissbein et al. 2013; Gillingham & Sweeney 2010); and (ii) policies never evolve in a vacuum but are often layered on top of existing policies thus impacting on policy mixes' temporal characteristics, such as their 'consistency' (Howlett and Rayner, 2013, see e.g., 2007). While several conceptual studies on policy mixes have been published recently (Flanagan et al., 2011; Rogge and Reichardt, 2016) there is very little empirical work apart from single case or small-n studies (Kern et al., 2017; see e.g., Kern and Howlett, 2009). In consequence, there is a lack of studies systematically comparing policy mixes and their dynamics and of empirical analyses of policy mixes' effect on policy outcomes across a larger set of cases. Also, the above described instrument design literature has been relatively de-coupled from the policy mix literature, leading to conceptual, theoretical, and empirical ambiguity.

In this paper, we address this gap by conceptualizing the policy design features of *intensity* and *technology specificity* at the policy mix tier as well as proposing a measure of policy mix *balance*. We also develop measurements for these three concepts and empirically apply them to renewable energy policy mixes in nine OECD countries. In doing so we aim to answer the following two research questions: First, how do renewable energy policy mixes differ between countries and over time regarding their design features intensity and technology-specificity as well as their balance? And second, to which extent can these differences explain observed variation in the diffusion of different renewable energy technologies?

Answering these research questions requires confronting a prevalent conceptual and methodological challenge: 'the dependent variable problem in the study of policy change' (Howlett and Cashore, 2009). We address this challenge by systematically building up our conceptualizations and measurements bottom-up: starting from identifying design features of individual policy instruments we aggregate these individual policy instruments at the policy mix tier which allows for the systematic evaluation of policy mix designs and characteristics. Our aim is to arrive at an empirical measurement of dynamics across these dimensions of policy output and analyze their effect on policy outcome. To this end, we develop a comparative dataset of 522 policies in the nine countries and apply a modified version of Schaffrin et al.'s (2015, 2014) '*Index of Policy Activity*' (IPA) that brings together a generalizable conceptualization and measurement of policy intensity with the context-specific design feature of technology-specificity.

While partly focusing on specific concepts, such as the policy design feature of technology-specificity and the policy mix characteristic of balance, our approach also provides general assessment of individual policy instruments (via intensity) and policy mix design (via aggregating individual policy instruments). We thus see our approach as a contribution to developing a toolbox for creating comparable assessments and datasets of complex policy mixes. In turn, this allows for further research into identifying elements of policy mixes that contribute decisively to inducing socio-technological transitions. Also, our empirical findings, by highlighting diverging patterns of policy mixes' design features and their effects, can help inform improving the 'patching' of policy mixes (Howlett and del Rio, 2015; Howlett and Rayner, 2013; Kern et al., 2017). Overall, we aim to contribute to bridging the archipelagos between research communities in innovation and policy studies.

The paper is structured as follows: Section 2 provides a background on the literature on policy instrument design and particularly the specific design features intensity and technology-specificity (2.1) as well as the literature on policy mixes (2.2). Based on this review we develop a conceptualization of design features and characteristics at the mix tier (2.3). Section 3 provides the sampling logic for our nine countries, introduces our methods to address both research questions, and provides details on the data used. Section 4 describes our results regarding the dynamics (4.1) and effects (4.2) of policy mixes' design features and characteristics. Section 5 discusses these results and proposes avenues for future research, while Section 6 concludes the paper.

2. Theory

2.1 Design features at the policy instrument tier

There is a long tradition in economics of ex-ante and ex-post analyses of policy instruments' effects on technological change. Most of this literature has (and arguably still is) focused on the question which instrument types are most effective and efficient in inducing innovation and diffusion of new technologies. For instance, with regards to climate-change mitigation-related policy, there are many studies analyzing the question whether a carbon emission tax or a cap-and-trade policy instrument is more efficient in inducing (long-term) carbon emission reductions (see e.g., Goulder & Schein 2013; Wittneben 2009; Stavins 2008). Similarly, with regard to innovation, many studies analyze whether R&D tax credits are more effective in inducing corporate innovative activity than grant schemes for R&D (see e.g., Tassey 1996; Guellec 2003). Most of these debates are not settled. Many innovation scholars argue that this is the case as the instrument type per se is not decisive in explaining policy outcomes but that the design features of an instrument also need to be considered (Ashford et al., 1985; Jenner et al., 2013; Kemp and Pontoglio, 2011; Norberg-Bohm, 1999; Schmidt et al., 2012b; Yin and Powers, 2010). These scholars propose to analyze an instrument's stringency, predictability, enforcement and other design features rather than to simply compare different instrument types (see e.g., Kemp and Pontoglio, 2011). Yet, both the discussed list of relevant design features as well as their conceptualization and measurement are contested. One design feature, however, is consistently referred to in these debates: policy stringency. While seemingly being used synonymous to overall policy strength, this design feature remains underspecified as it is not discussed in relation to other design features and applied in an ad-hoc manner for specific policy instruments such as renewable portfolio standards (Carley and Miller, 2012; Yin and Powers, 2010). Interestingly, this has a substantial similarity to the use of stringency in environmental policy research where it is typically associated with regulatory instruments and measured as levels of air pollution or water quality standards (e.g., Holzinger et al., 2011).

An alternative approach to these limited conceptualizations and measurements of design features can be found in the extensive literature on public policy change. While not offering practical operationalization, the landmark studies by Hall (1993) and Howlett & Cashore (2009) have stimulated a debate about 'the dependent variable problem in the study of policy change'. Knill et al. (2012) have introduced the concept of 'policy intensity' that aims at going beyond Hall's (1993) scheme by identifying a policy's scope, i.e. the number of cases or addressees covered by a specific policy instrument. Yet, this initial conceptualization of intensity remains linked to regulatory policy instruments, leaving open the question whether it can be meaningfully applied across other policy instrument types. Against this background, Schaffrin et al. (2014, 2015) propose instead to focus on more general policy dimensions that allow measuring intensity in a broader sense. They propose six intensity indicators – *objectives*, *scope*, *integration*, *budget*, *implementation*, and *monitoring* – that any policy comprises with varying degree of distinctiveness. Taken together, these indicators reveal the amount of resources, effort and political activity that is invested in or allocated to the policy under investigation. In terms of measurement, these indicators inform a content-based coding procedure that allows for the production of a comparable dataset of policy's design features which can also be aggregated to an equally weighted measure of a policy's intensity: the *Index of Policy Activity* (IPA). This comprehensive measure of policy intensity can then be compared across cases and over time.

Besides the general policy design feature of intensity, there are important features specific to technological change and transitions. A prominent debate among economists and innovation scholars concerns whether policies should be designed in a technology-neutral or technology-specific fashion.[1] Scholars supporting technology-neutral instruments, i.e., instruments "encouraging all efforts that achieve specified objectives without focusing on a particular approach" (Jaffe et al., 2005, p. 171), argue that policy makers should avoid selecting specific technologies to be supported (see e.g., Krugman 1996). In the view of these scholars, policy makers act on the basis of political considerations instead of technology- and market signals (Aghion et al., 2009). Other scholars argue that due to path-dependency technology-neutral policy instruments can result in the early lock-out of promising technologies (Aghion et al., 2009; Arthur, 1989; del Río González, 2008). As markets often select on short-sighted basis, supposedly neutral deployment policy can result in an indirect selection of a technology by markets (Azar and Sandén, 2011; Schmidt et al., 2016). To counter this effect, (complementary) technology-specific instruments are proposed (del Río, 2017; del Río González, 2008; Gawel et al., 2017; Sandén and Azar, 2005; Schmidt et al., 2012b; Van Benthem and Gillingham, 2008; van der Zwaan et al., 2002; Vogt-Schilb and Hallegatte, 2014).

More recently, a group of scholars have argued that the neutral-specific dichotomy is overly simplistic. In their opinion, the debate "should be replaced by a discussion about how technology specific the policies should be." (Azar and Sanden 2011, p. 137). Policies "can be specific (or neutral) only on a certain technological hierarchy level: a policy that is 'specific' on a certain technology level might still be 'neutral' (or rather 'unspecific') on the hierarchy level below" (Schmidt et al. 2016, p. 1966). For example, while an economy-wide carbon pricing policy is technology-neutral, a renewable portfolio standard, mandating power generators to produce a certain share of electricity from renewable sources, is specific to the extent that the power must be renewable but is neutral regarding the type of RET. Other instruments like feed-in tariffs are typically differentiating between RET but are neutral regarding different sub-technologies (e.g., crystalline silicon vs thin-film PV). Recent literature shows that the level of technology-specificity of an instrument can determine which technologies are picked by the markets, i.e., where investments into R&D and technology diffusion go to (del Río González, 2008; Hoppmann et al., 2013; Polzin et al., 2015; Schmidt et al., 2016). Technology-specificity therefore arguably is a key design criterion for policies aiming at inducing a low-carbon transition of the energy sector (Azar and Sanden 2011). It is thus the more surprising that most analyses of the output and

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[1] For a more detailed review of the debate see e.g., Azar and Sanden (2011) and Schmidt et al. (2016).

outcome of energy policy do not adequately reflect this highly important policy instrument design dimension. In this paper, we therefore focus on two policy design features: the general feature *intensity* and the transitions-related feature *technology-specificity*.

2.2 Policy mixes for socio-technical transitions

While the debate on instrument types and designs to induce socio-technical transitions is still in full swing, a growing number of scholars – especially those analyzing socio-technical transitions – argues that the overall policy mix needs to be considered (Flanagan et al., 2011; Howlett and del Rio, 2015; Kern and Howlett, 2009; Rogge and Reichardt, 2016). Here, we highlight two important reasons that speak for a focus on mixes instead of individual instruments: (i) the multiple failures and targets involved in technological change or transitions; (ii) the realities of the policy process, which typically results in 'layering' of policies. We elaborate on these reasons in the following.

First, innovation economists stress that there are multiple market and system failures involved in technological change (Lehmann (2012) provides an overview over the literature concerned with pollution control). Amongst others, positive externalities related to R&D and learning-by-doing in the form of knowledge spillovers, market power issues, negative externalities (such as carbon emissions), and network externalities have been identified by economists (for an overview see e.g., Gillingham and Sweeney 2010). Similarly, innovation systems scholars have identified multiple types of bottlenecks that block the functionality of innovation systems (Bergek et al., 2008; Hekkert and Negro, 2009). Also researchers analyzing investment risks of new technologies find multiple risks which hamper investment flows (Bürer and Wüstenhagen, 2009; Schmidt, 2014; Waissbein et al., 2013). These literatures highlight that there is no single instrument that can address all of the market failures, bottlenecks, or risks because typically different instrument *types* are required. For instance, R&D support policies ('technology-push'), negative externality-internalization, and information-related policies might have to be combined in a *balanced* policy mix. In the field of energy transitions, it is furthermore important to keep in mind that energy policy typically serves multiple policy goals. Besides addressing environmental and social concerns, such as climate change and air quality, energy policy aims at affordability security of energy services. Often, energy policy also entails industry policy goals (Schmidt and Huenteler, 2016). Catering to various goals also necessitates multiple instruments (Howlett and del Rio, 2015). Accelerating and re-directing technological change in the energy sector is thus not a question of individual instruments but requires a mix of policy instruments (Flanagan, Uyarra, and Laranja 2011; Schmidt, Schneider, and Hoffmann 2012; Schmidt et al. 2012; Kern and Howlett 2009; Reichardt and Rogge 2016). In consequence, policy makers needs to design a mix, which caters to various goals and addresses the multiple barriers and failures in reaching those goals, and thereby enables low-carbon energy transitions.

Second, regarding the design of such policy mixes, many studies explicitly or implicitly assume that decision-makers have unlimited 'degree of freedom' in their design choices. This assumption can be misleading since it downplays the importance of temporal legacies in existing policy mixes while overestimating possibilities of complete policy ‘replacement’, i.e. designing all elements of the mix *de novo* (Hacker, 2004; Thelen, 2003). In reality, policy-makers typically confront a situation in which an already existing policy mix is in place and must be incorporated, as it cannot be easily discarded. Existing policy mixes have emerged from gradual, often incremental processes of change or successive reformulation, the most prominent of these being ‘layering’. In the literature (Beland, 2007; Howlett and Rayner, 2007), this is described as a process whereby new policies are simply added to an existing mix without abandoning previous ones. Despite the prevalence of the term in the literature ‘layering’ as an empirical phenomenon is not clearly defined (Heijden, 2011). Typically, researchers assume that ‘layering’ results in unintentional or non-designed policy mixes that impede what is being described as the ‘consistency’ of policy mixes, i.e., the ability of multiple policy tools to reinforce rather than undermine each other in the pursuit of individual policy goals (Howlett and Rayner, 2013; Kern et al., 2017). Yet, while conceptually clearly defined, consistency is difficult to measure empirically, leaving researchers only with the option of assessing it by interviews or other qualitative means (Kern et al., 2017; Rogge and Reichardt, 2016). Interestingly, Daugbjerg and Swinbank (2015) argue for a different, more positive take on layering: building on Patashnik’s (2003) work on the political sustainability of policy reforms, they discuss how adding *new* layers in the form of new policy *instrument types* can reflect pressure for dismantling from actors that are negatively affected by the original policy. Layering thus can turn into a strategy where “policy designers can change the distribution of costs and benefits by adding new policy instruments […] and thus change the interest configuration around policy” (p. 268). This argument has a striking similarity with the arguments made above for a ‘balanced’ approach in policy mix design where different policy instruments are needed to address multiple types of bottlenecks. In addition, recent policy design research has begun to stress the need for more realistic design strategies to promote more consistent and coherent policy mixes in the form of ‘patching’ (altering only specific elements of existing mixes) in circumstances where ‘packaging’ (introducing entirely new policy mixes) is not viable (Howlett and del Rio, 2015; Kern et al., 2017). Against this background, we focus on the ‘balance’ of a policy mix in relation to the instrument types used, which can be empirically measured in a high-n analysis.

2.3 Merging perspectives: policy mix design features and characteristics

Having reviewed the evolving academic debates around policy design features and policy mixes, the question remains why these debates are conducted more or less independent of each other. If policy instrument design features matter, they should also represent an important feature of the overall policy mix. Similarly, policy design features could provide an important reference point for researchers coming from a policy mix perspective and might even serve as a structuring element for empirical analyses. However, while merging the two perspectives would appear as a natural next step to move forward academic debates, current research is hampered by the lack of comprehensive measurement approaches that deliver comparable data assessing complex policy mixes. In their agenda-setting paper, Howlett and del Rio (2015) highlight the failure of existing policy mix studies to adequately define the object or dependent variable of their analyses, namely policy mix itself. They point out that “although thinking about the design of policy portfolios has been at the forefront of much current research work on policy design […], existing studies of such bundles of tools do not use consistent terminology and fail to define the dependent variable carefully enough” (p.1234). Because of this failure, “the cumulative impact of empirical studies has not been great, theorization has lagged and understanding of the mix phenomena, despite many observations of its significance, has not improved very much over past decades” (ibid.). Our study is a first attempt to improve our understanding of policy mixes, by providing a bottom-up conceptualization of policy design features at the mix tier. For the design feature intensity, we use the approach by Schaffrin et al. (2015), and measure the intensity of each individual policy in a mix. We also identify the technology-specificity of each policy (compare ‘Policy instrument tier’ in Figure 1). We then combine this information so that each policy’s intensity contributes to the policy mix’s intensity at the respective technology-specificity level (compare ‘Policy mix design features’ in Figure 1). The policy mix balance is conceptualized as the distribution of the instrument types within the mix (at each technology-specificity level) (compare ‘Policy mix characteristic’ in Figure 1). To do so, we identify the instrument type(s) of each policy at the instrument tier.

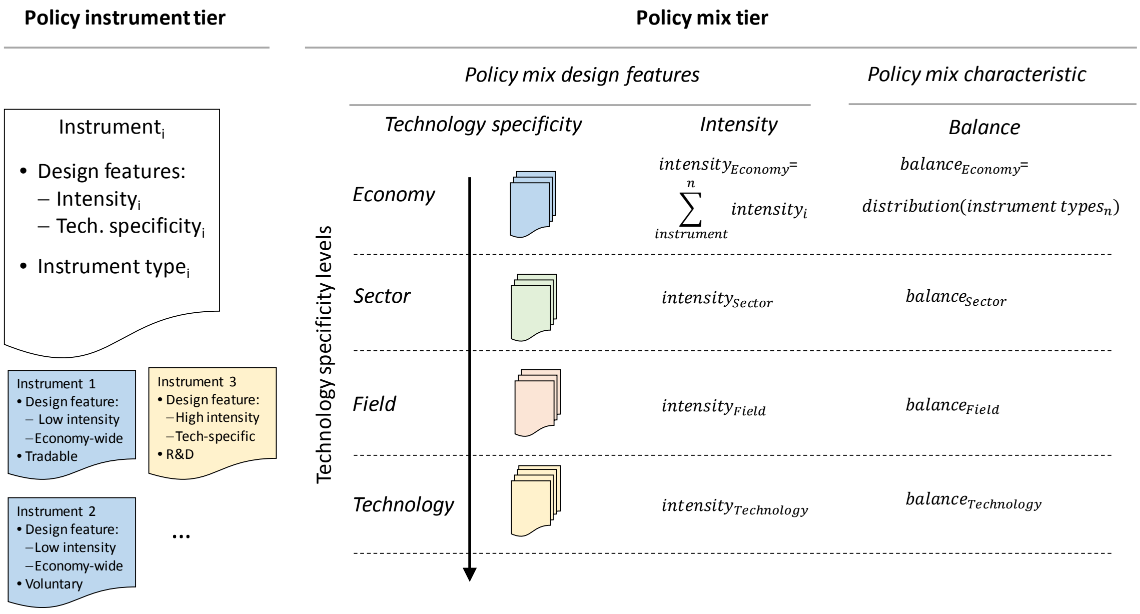

Figure 1: From policy instrument design features and instrument types to policy mix design features and mix characteristics

Note that we do not aim to analyze the mutual interaction of policies within a policy mix. While many policy mix studies aim at analyzing instrument-interaction, a better understanding of the temporal dimension of policy mix development is also very important. As Howlett and del Rio (2015) point out, many existing policy mixes have developed in a haphazard fashion through processes of policy layering rather than by conscious and planned policy design choices (compare 2.2). These processes need to be better understood, empirically as well as conceptually, before focusing attention on questions of optimal policy design or the right sequencing of policy instrument choices. In their words, “design analyses must extend beyond questions of tool synergies and optimal design to consideration of how and why mixes change over time” (p. 1235). Our contribution to the debate is to look at *how* mixes change, by focusing on *intensity* and *technology specificity* as distinct design features at the policy mix tier as well the mix characteristic *balance*. We thus go beyond studies that analyze policy mixes on the basis of merely counting policy instruments in a mix without considering the intensity of these individual policies (e.g., Kern et al., 2017). We also go beyond the few extant analyses that systematically consider technology-specificity that typically focus on few selected instruments and do not analyze the entire policy mix (Gawel et al., 2017; see e.g., Hoppmann et al., 2013; Lehmann and Söderholm, 2016). More specifically, our approach improves our understanding of which renewable energy technologies depend on more technology-specific policy *mixes* and which do not. In line with the literature on the instrument-tier level, we assume that more mature technologies (which are more competitive with established technologies) can become successful against the background of policy mixes that feature a low technology-specificity whereas less economically mature technologies need the support of more technology-specific policy mixes. By introducing and empirically analyzing the policy mix balance, we overcome the problems of measuring policy mix characteristics related to policy outcome, such as consistency (see 2.2).

3. Case Selection, Method, and Data

3.1 Case Selection

As (in most countries) the national level remains most important for the development of energy policy, we focus on this level of analysis.[2] To select our cases, we follow a diverse-case selection strategy (Gerring, 2007; Rohlfing, 2012; Seawright and Gerring, 2008), an approach intended to maximize variance across a dimension (or dimensions) of interest. The nine countries analyzed in this paper are Australia, Austria, Canada, Germany, Ireland, New Zealand, Spain, Switzerland and the United Kingdom (UK). We primarily sampled countries on the opposite end of the spectrum of renewable energy technology diffusion (excluding hydro, see Figure 2): Germany has been very successful in terms of the diffusion of low-carbon energy technologies, with over 40 percent of installed electricity being renewable in 2014. Spain, the United Kingdom, and Ireland reach a moderate percentage of around 25 percent. Technology diffusion in all other countries has been rather low with shares between 10 and 20 percent in Austria, New Zealand, and Australia, or very low, with shares under 10 percent in Canada and Switzerland. These cases also produce variance across other dimensions: we include five EU

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[2] We acknowledge that sub- and supra- national policies are also relevant in energy transitions.

member states and four non-EU countries as well as small(er) and large(r) countries. Also, the cases differ in terms of their political-institutional setup with federal and unitary countries being represented, two- as well as multiple-party systems as well as different types of democracies ("Westminster" vs. "Consensus" democracies, see Lijphart, 2012). Our sample thus includes a very diverse set of cases across various dimensions.

3.2 Method

Assessment of Policy Intensity

In this paper, we apply the measurement approach introduced by Schaffrin et al. (2015, 2014), the Index of Policy Activity (IPA) to measure policy intensity at the instrument tier. The IPA approach is based on a content-based coding procedure to be applied to each policy under investigation (see Appendix 2). The approach allows for the aggregation of a score (weighted number) of a policy instrument's intensity; summing up the score of all instruments per country and year then provides the overall IPA, i.e. a score for the overall policy mix. For details on the coding, see Section 3.3. As comparisons with other existing measurement approaches have shown, IPA provides a valid and reliable assessment of policy instruments' content (Schaffrin et al., 2015). As a modification of the approach, each individual policy's technology-specificity is assessed as well.

Assessment of Technology-Specificity

Policies aim at different technology hierarchy levels, allowing to operationalize technology-specificity in a straightforward manner by noting which technology level a policy is aiming at. We distinguish between four levels: (1) economy, (2) sector, (3) technology field, (4) technology.[3] The four levels can be described as follows:

- An *economy-level* policy is one that (potentially) affects all sectors and their technologies. Examples of this kind of policy are informational campaigns to increase climate awareness and broad carbon taxes that treat all marginal changes in emissions equally.
- *Sector-level* policies are those policies that target climate-relevant technologies associated with a particular sector of the economy. The classic example of this level of specificity is a policy that targets all forms of power generation, transmission and distribution, but does not extend to other sectors such as industrial emissions or energy efficiency in buildings. Here we focus on the power sector.
- *Field-level* technology-specificity encompasses policies that target or apply to particular categories of technologies within a sector. An example of field-level policies within the power

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[3] We follow Schmidt et al. (2016) in the definition and delineation of these levels.

sector include those that specifically seek to promote renewable power generation (focus of this paper), such as renewable portfolio standards.

- Once policies become focused on a single technology, they are coded at the *technology-level* of specificity. Many feed-in tariffs fall into this category, as they pay different premiums for different renewable energy technologies, such as wind, solar or biomass.

In order to systematically differentiate between energy technologies at the technology level, we follow the definition provided by the European Patent Office.[4]

Assessment of policy mix balance

We define policy mix balance by the dispersion of policy instruments across different instrument types. Each policy is coded along its instrument type. We follow the International Energy Association's categorization of policy instruments along nine different types (compare Schaffrin et al. 2014): education, financial, incentive, investment, R&D, regulation, tradable, voluntary, framework. For a definition of each instrument type, see Table 3 in the Appendix. In some occasions, policies span across instrument types (e.g., a law that combines an incentive with a regulatory element). Such policies are counted in each respective instrument type when calculating the policy balance. In order to estimate the balance of the policy mix across instruments, we use the 1-Simpson Index (also called Gini-Simpson Index), which was developed in ecology to estimate the concentration of populations across different species (Hill, 1973; Simpson, 1949). Applied to policy mixes, it is expressed by the following formula:

$$1-\lambda = 1-\sum_{instrument_{i=1}}^{n} p_i^2 = 1-\frac{\sum_{instrument_{i=1}}^{n}(instrument_i * (instrument_i - 1))}{\sum policies * ((\sum policies) - 1)}$$

The 1-Simpson index ranges from zero to one. Applied to policies in the policy mix it represents the probability that two policies which are randomly picked from a policy mix are of the same instrument type. In other words, if the index is one, the likelihood is that the policies are of different instrument types is 100%. This represents a policy mix that is very balanced across instrument types. With a lower Gini-Simpson index, the likelihood decreases that the two policies are of different instrument types, representing a lower balance (or higher concentration) of policies across instrument types. We calculate the Gini-Simpson index on each technology-specificity level, thereby obtaining a design-specific policy mix balance.

Assessment of Policy Mix Effects – Regression Analysis

In order to address our second research question, for each country we regress the diffusion of new renewable energy technologies on the intensity of the policy mix at each technology-specificity level.

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[4] More details can be found at: http://www.epo.org/news-issues/issues/classification/classification.html

At the technology-level, we also include the sum of the intensity for other technologies than the technology analyzed in the respective regression.[5] In a second step, we replace the mere intensity by the interaction term of the intensity and the policy mix balance at each technology specificity level. In other words, the intensity is discounted with increasing instrument-concentration of the policy mix.

As dependent variables, we use the percentage of installed capacity of biopower (i.e., biomass- and biogas-based electricity production capacity), wind (including on- and off-shore), and solar photovoltaics (PV) in all electricity production capacity.[6] We choose these technologies as they represent leading renewable energy technologies and have high long-term potential. Furthermore, in the observed period (1998-2013), they featured major differences in economic competitiveness with non-renewable energies, with biomass being most competitive and PV least competitive during the observed period. One would therefore expect technology-specificity of the policy mix to be increasingly important when moving from biopower via wind to PV. We use a capacity indicator as capacity is the most accurate proxy for technology diffusion (Popp et al., 2011). Figure 2 summarizes the (non-hydro) renewable generation capacity shares as percentage of totally installed capacity in each country over time. For a technology-specific representation, see Figure 1 in the Appendix. We apply panel regression with ordinary least square estimation and lag the dependent variable by one year. One observation in our regression thus represents one country-year. We use country-dummies to cover all country-specific non-dynamic explanatory factors (such as resource-availability or political institutions). We include net energy imports as percentage of total energy use (to cover energy dependency) as well as GDP (to cover scale effects) as dynamic control variables on a country level (compare Polzin et al., 2015). At the global level, we include Brent oil prices (annual average) as control variable, approximating fossil fuel prices, and thus serving as alternative explanatory factor for renewable technology diffusion. We also include a time dummy to account for general trends and technological progress. Table 1 summarizes the variables' descriptive statistics in our sample. Table 1 in the Appendix provides the variables' correlation data.

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[5] E.g., when analyzing the diffusion of wind, we include the IPA (wind) as well as the IPA of other technologies than wind.

[6] In the analysis of the policy mix (research question 1) we also include geothermal and hydro power. However, we do not provide own regression analyses due to the limited variance on the dependent variable (compare Polzin et al. 2015).

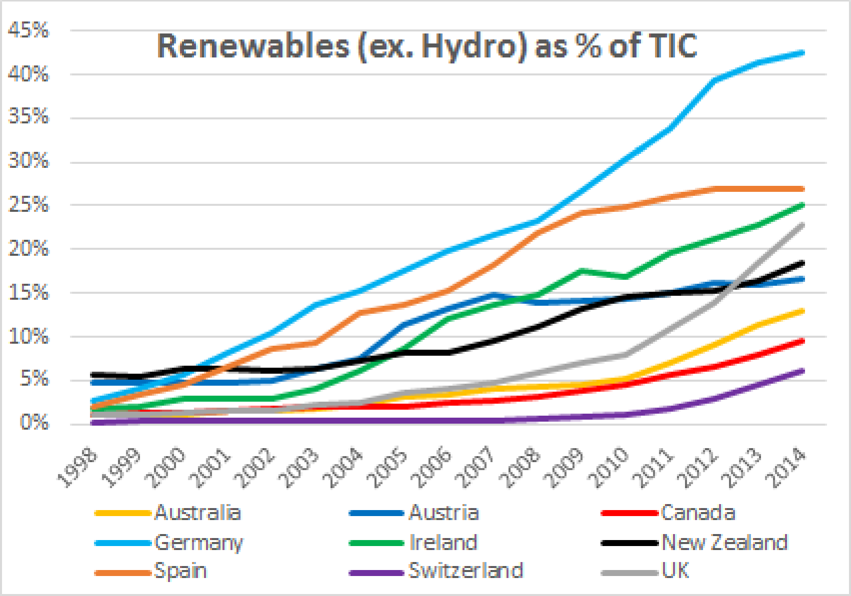

Figure 2: Share of renewable power generation (excluding hydro) as percentage of totally installed capacity (TIC) over time

Table 1: Variable overview and descriptive statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
Wind as % of Installed Capacity	6.15	6.68	0.00	24.36
PV as % of Installed Capacity	1.34	3.30	0.00	19.52
Biomass as % Installed Capacity	1.22	1.78	0.00	8.11
Intensity Economy	0.62	0.94	0.00	4.00
Intensity Sector	0.62	0.71	0.00	2.97
Intensity Field	0.88	0.70	0.00	2.95
Intensity Tech – Total	3.46	2.73	0.00	12.92
Intensity Tech – Biopower	1.81	1.81	0.00	7.12
Intensity Tech – Wind	1.49	1.39	0.00	6.14
Intensity Tech – PV	1.75	1.73	0.00	7.34
Intensity*Balance Economy	0.50	0.75	0.00	3.35
Intensity*Balance Sector	0.56	0.62	0.00	2.75
Intensity*Balance Field	0.73	0.60	0.00	2.62
Intensity*Balance Tech – Total	2.88	2.28	0.00	10.34
Intensity*Balance – Biopower	1.52	1.50	0.00	6.10
Intensity*Balance – Wind	1.29	1.17	0.00	5.29
Intensity*Balance – PV	1.44	1.40	0.00	5.57
Net Energy Imports as % of energy use	19.43	69.49	-26.81	90.68
Brent Oil Price (in USD per barrel)	61.31	34.57	13.40	111.60
GDP Total (in trillion USD)	1.06	1.00	0.27	3.87

3.3 Data and coding

Data on policy instruments was compiled by collecting information from public sources: the *Policies and Measures Databases* of the International Energy Agency and the *Climate Policies and Measures in Europe* Database of the European Energy Agency. We also used UNFCCC National Communications and other national documents such as governmental reports to add further policy instruments not listed in the public datasets or complement information on policy instruments' characteristics. In total, 522 policy instruments with varying numbers per country and per year were analyzed. The coding of policy instruments was done according to the scheme described in Table 2 of the Appendix by two coders and checked by the authors of this study to increase the validity of assessment. If differences in the assessment of a policy instrument arose between the coders, the value of the debated intensity measure was set in a group discussion. The standard IPA dataset then was complemented with information regarding technology-specificity (see 3.2). For both research questions, we sum up the IPA of all policy instruments on each technology-specificity level. Data on the renewable energy capacity (RQ2) stems from the OECD Energy database[7]. Data on control variables was retrieved from the World Bank's World Development Indicators database[8] (net energy imports and GDP), as well as Quandl.com (Brent prices).

4. Results

4.1 Policy mix dynamics

Policy mixes' intensity and technology specificity

The results of our analysis regarding the policy intensity dynamics on the technology-specificity levels are depicted in Figure 3 and generally reveal large variance across our cases. Also, the dynamics differ on the within-case level across the various specificity levels. In the following we briefly describe general trends across all nine countries.

The Australian policy mix is characterized by relatively low to medium policy intensity. While policies span all four technology-specificity levels, intensity at the field and technology level is highest, with the former increasing since 2010 and the latter increasing until 2012. Similarly, intensity in Austria's policy mix is low to medium. While economy level policies are of no relevance, policies' intensity at the sector, field and technology levels is increasing over time with only some volatility. The picture is similar in Canada, with economy level policies featuring higher intensity than in Austria, though. New Zealand's policy mix intensity is rather low in comparison and seems to be mostly focused on the economy and sector levels, with increasing intensity on the latter. There is relatively little intensity at the other levels, only some, yet low and volatile, at the technology level. This contrasts sharply with the results in Spain, where intensity is highest on the technology and field levels. Especially at the technology level, there is a strongly increasing trend over time. There is no observed policy at the economy level in the respective period, intensity at the field level since 2004 is medium, and on the sector level intensity increased only very recently. In Germany's policy mix, intensity is relatively high and spread across all four technology-specificity levels, with highest intensity at the technology level. Here, we observe a trend of increasing intensity to very high values, which, however, seems to stagnate since 2009. On the sector and technology field level, intensity started to increase later and stagnated quickly at medium values. Intensity at the technology level in Ireland's policy mix is similar to that of Germany, however, leveling

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[7] https://data.oecd.org/energy.htm

[8] http://data.worldbank.org/data-catalog/world-development-indicators

off after 2007. Intensity on the other three levels only reaches low to medium scores. Switzerland's policy mix intensity is almost entirely driven by the technology level, with medium but increasing values of intensity. Finally, the results in the UK show a very inconsistent picture and high volatility across all levels. After an early start and increasing intensity at the sector and field levels, intensity decreased from 2006 and 2009, respectively. An almost contrasting pattern can be observed at the economy level, where intensity increases relatively late and becomes rather stagnant or decreasing after a spike around 2008-2010. Technology level policy intensity is increasing to relatively high levels until 2011, when it starts to decrease.

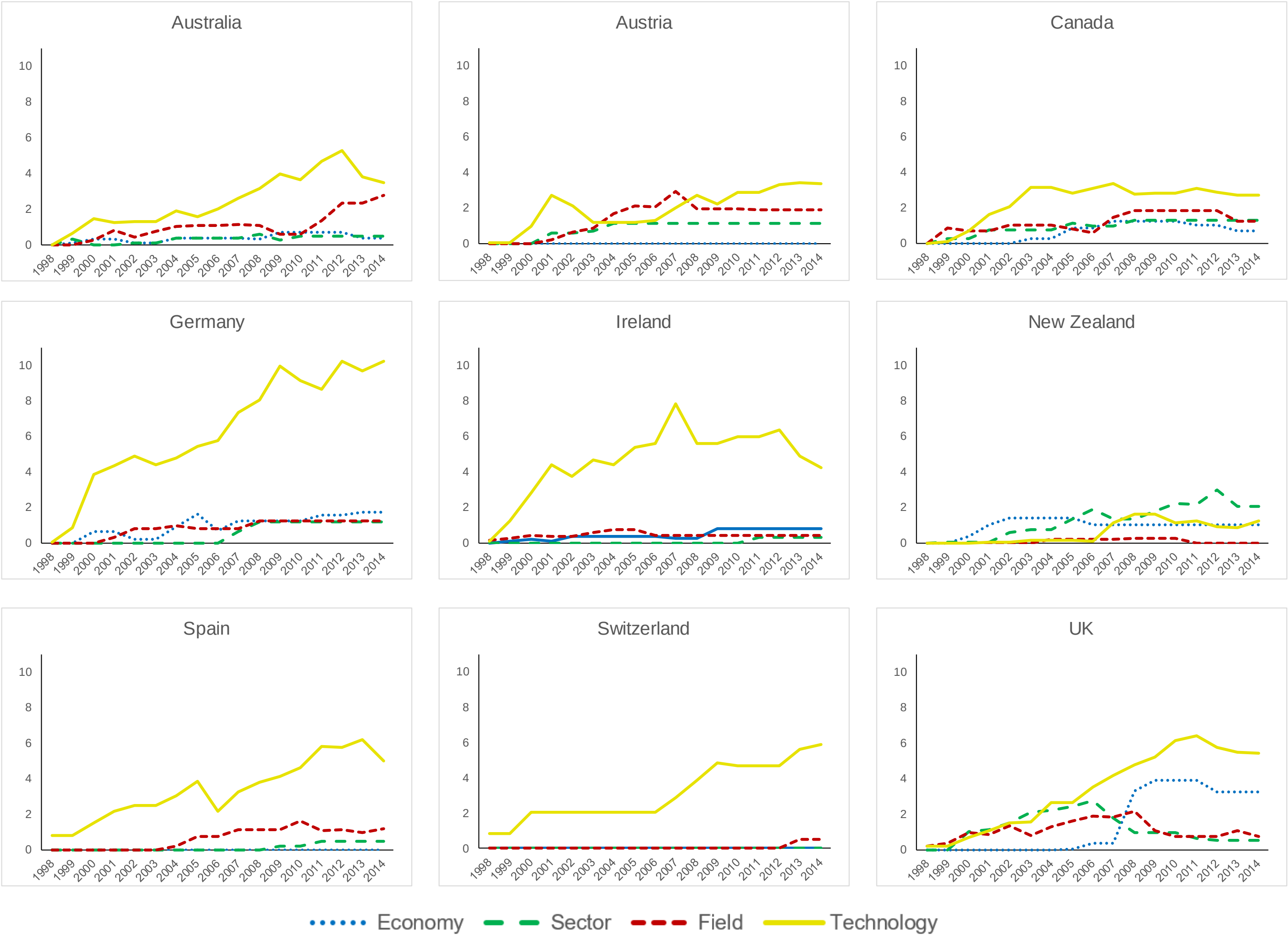

Figure 3: The technology-specificity of renewable energy-related policy mixes in the nine analyzed countries. The values depict the IPA per year on each of the four specificity levels: Economy, Sector, Field, and Technology.

At the technology level, we can differentiate between the various renewable energy technologies that are targeted by the instruments in a policy mix. Figure 4 provides an overview over the trends for the different technologies. Interestingly, we observe no country that focuses on only one or two technologies. In fact, all countries, except for Spain and Canada, which did not have dedicated geothermal policies, and New Zealand, which did not target policies specifically at wind and PV, support five renewable energy technologies (biomass, wind, and PV plus geothermal and hydro). Most countries, especially Canada (except for geothermal) and Switzerland seem to target technologies rather equally. Only Ireland features less balance between technologies.

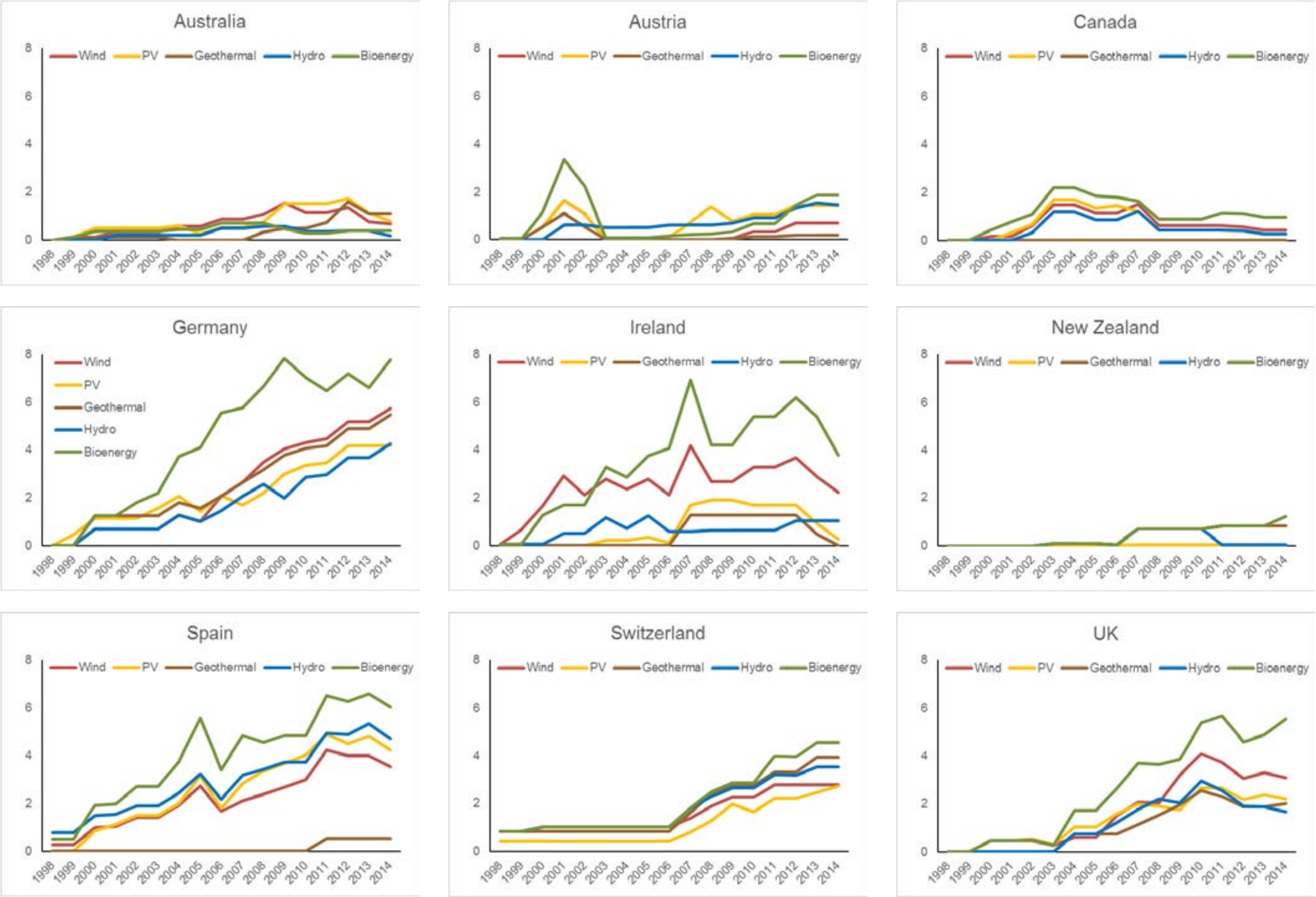

Figure 4: Policy intensity of the policy mix at the technology level

Policy mixes' balance regarding instrument types

The results of our analysis regarding the policy mix balance are shown in Figure 5, and reveal interesting dynamics over time and across cases. In the following, we briefly describe general trends and peculiar observations in all nine countries.

Australia features a generally relatively stable and well-balanced policy mix. The mix is most unbalanced at the technology level, with its very high number of instruments. Interestingly, despite the clear dismantling of policies across all levels after 2012, the balance of the mix only increases slightly. Similarly, in Austria, the balance of the policy mix remains relatively stable over time despite a long trend of addition to the mix on the technology level from 2007 to 2013. The only exception in this very stable mix is the marked dip in technology level balance in 2000 when the mix was dominated by three financial instruments, with only one other policy instrument in place. We observe a similar dip in Ireland but at the economy level. Here, the huge swing in balance is caused by a one-sided reliance on education policies from 1999 to 2002, after which more instrument types are added which leads to a leveling out of the balance curve.[9] Generally, Ireland's policy mix is built around fewer policy instruments, primarily belonging to the technology-level. Over time, balance at this level incrementally deteriorates, even while the number of policies is being reduced (2007-2014). Canada's policy mix balance remains stable after a first consolidation phase until 2005/6. Here the degree of balance across technology-specificity levels is also very similar, a finding that stands out across the sample (the only other similar case being Germany). Similar to Ireland, the last seven years in our sample reveal a clear trend of dismantling in Canada, primarily at the economy- and sector-level, which however hardly affects mix balance. The German policy mix is similar to the Canadian in that the degree of balance across all technology-level is similar after around 2006, yet on a slightly lower trajectory. The main driver for these lower numbers in comparison to Canada is the tendency for increasing the number of framework policies in the mix across all technology-levels. In New Zealand, the policy mix consists of only relatively few policies, similar to Ireland. New Zealand is also a country where the difference in balance across technology-specificity levels is rather high, with 2014 values of 0.90 and 0.84 on the technology- and sector-level being in contrast to the value of 0.67 at the economy-level. Spain reveals a very stable (and medium high) balance at the technology-level from the beginning of our time-frame and this despite continuous addition of new instruments to the mix. Also here, the balance at the technology-level remains stable even when elements of the mix are dismantled, as in 2006 and after 2012. In Switzerland, policy mix balance is notably less changing than in the other countries. In the first half of the observation period, up to 2006, the policy mix did not evolve further, leaving the difference in balance between the field- and technology-level unaltered. The addition of new instruments at the field-level in 2006 and later in 2013 are the only major instances where balance improved noticeably. Despite more additions of policies at the technology-level after 2006, balance remains largely unchanged at high values. Finally, the UK shows a rather unique pattern with both a large difference in balance across specificity-levels and clearer trends of deterioration of balance over time, specifically at the field-level. Here, the early dip in balance is due to an early focus on framework instruments (1998-2000) after which balance is increased by the addition of tradable and incentive policies until 2003. Thereafter a strong focus on tradable and regulatory instruments drives the above mentioned deterioration that only is stopped by the addition of (voluntary and incentive) policies after 2011.

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[9] Note that such major volatilities only occur when very few policies are in place.

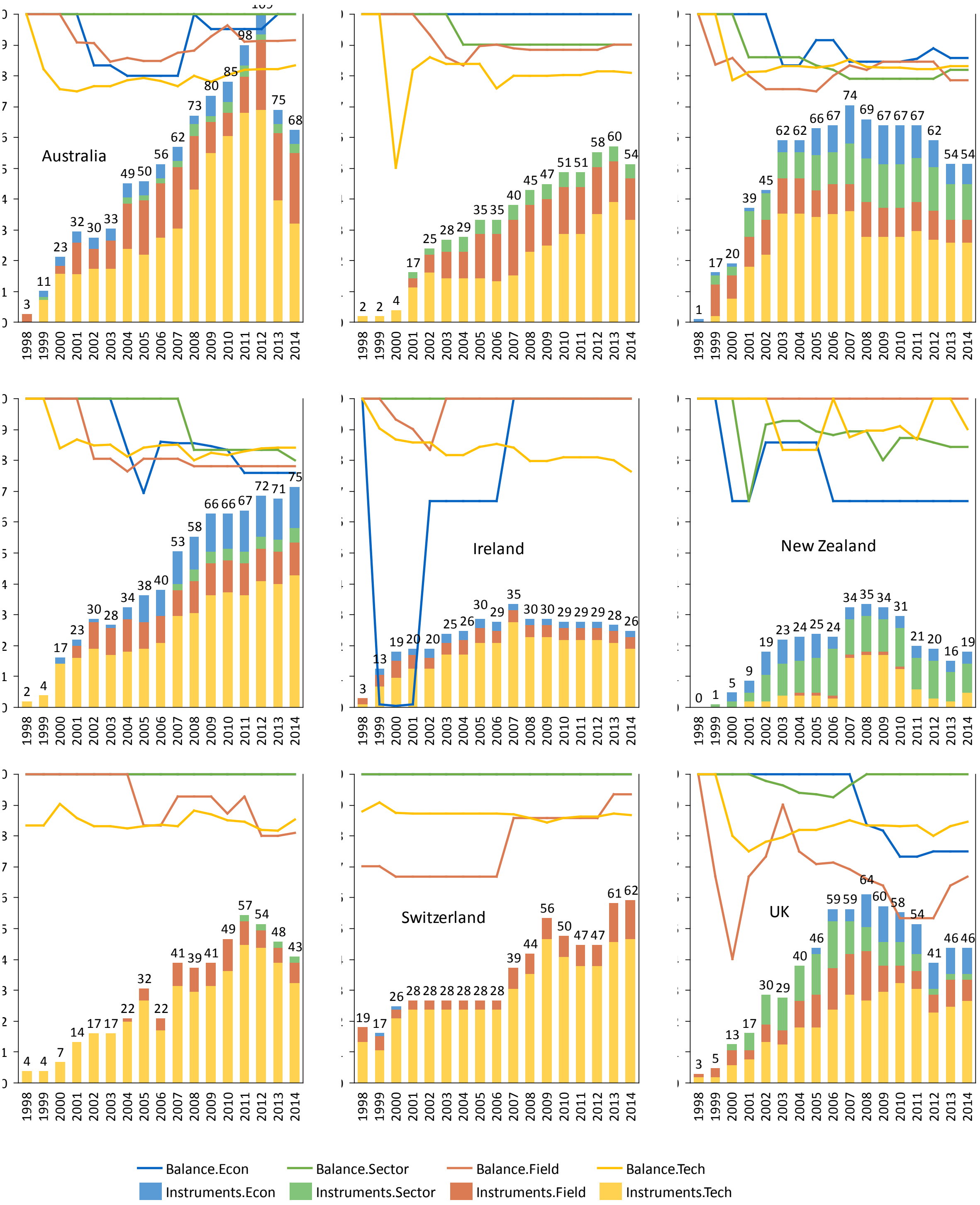

Figure 5: Instrument balance of the policy mix at the four technology-specificity levels. Lines represent the balance of the mix (left-hand axis), columns represent the number of policy instruments enacted (right-had axis)

4.2 The effects of the mixes' design features and characteristics on technology diffusion

While the results of the first step of our analysis reveal a strong variance of the technology-specificity across countries and time, we now turn to the effects of these differences. Table 2 summarizes the results of our regression analyses for biopower, wind and PV. The first column per technology (model 1, 3, and 5) reports the coefficients, significance and error bars of the specification focusing on the intensity of the policy mix at the four technology levels. The second column (models 2, 4, and 6) reports the specification of the interaction term of balance and intensity. Generally, we find that the interaction term only (slightly) improves the explanatory value of our regressions in case of the biopower model. The interaction-term specifications are therefore not discussed for the cases of wind (model 4) and PV (model 6). We observe that policies neither at the economy nor at the sector level had a significant effect on the diffusion of the three technologies (at $p<0.05$). On the opposite, we do observe a negative effect of these more technology-unspecific policies for wind. For biopower, policies at the field level seem to be important drivers of technology diffusion (for both specifications), which is in line with our expectations. Interestingly, technology-level policies do not score significantly for biopower. In contrast, wind and PV are only significantly positively affected by policies at the technology-level. This indicates that biopower – as a more economically mature technology during the observed period – was rather picked by markets if the policy did not differentiate between different renewable energy technologies. For wind and PV to diffuse, the policy mix needed to be more technology-specific, which was expected for PV. Other papers, which have focused on individual policies on the technology- (e.g., feed-in tariffs, FiTs) vs field level (e.g., renewable portfolio standards, RPS) – but not on the policy mix – found indications that wind (and biopower) would be picked by markets when field-level cornerstone policy instruments are enacted (Polzin et al., 2015; Schmidt et al., 2016). However, our results indicate that (additional) policies at the technology level might be necessary. This might be related to the fact that biopower is technically much closer to fossil fuel-based technologies. Often biomass is even simply co-fired in (existing) coal plants. Also their integration into the existing electricity system is much easier as they typically are dispatchable and non-intermittent. Wind, on the other hand, is a technology that differs in many aspects from incumbent power generation technologies, e.g., because of its intermittency. It therefore might require more additional instruments at the technology level, such as regulations mandating grid access and feed-in priority.

Table 2: Results of regression analyses

	Biopower		**Wind**		**PV**	
	(1)	(2)	(3)	(4)	(5)	(6)
Int$_{\text{Economy}}$	0.002		-0.022***		0.004	
	(0.002)		(0.004)		(0.005)	
Int$_{\text{Economy}}$* **Bal**$_{\text{Economy}}$		0.001		-0.015***		-0.008*
		(0.002)		(0.004)		(0.005)
Int$_{\text{Sector}}$	0.001		-0.029***		0.008*	
	(0.002)		(0.005)		(0.005)	
Int$_{\text{Sector}}$* **Bal**$_{\text{Sector}}$		-0.0001		-0.023***		-0.003
		(0.002)		(0.005)		(0.005)
Int$_{\text{Field}}$	0.009***		-0.003		-0.005	
	(0.002)		(0.005)		(0.005)	
Int$_{\text{Field}}$* **Bal**$_{\text{Field}}$		0.009***		-0.007		-0.007
		(0.002)		(0.006)		(0.005)
Int$_{\text{Tech.i}}$	0.001		0.007**		0.016***	
	(0.001)		(0.003)		(0.003)	
Int$_{\text{Tech.i}}$* **Bal**$_{\text{Tech.i}}$		0.001		0.007*		0.012***
		(0.001)		(0.003)		(0.003)
Int$_{\text{(1-Tech.i)}}$	0.001		-0.002		0.005*	
	(0.001)		(0.003)		(0.003)	
Int$_{\text{(1-Tech.i)}}$* **Bal**$_{\text{(1-Tech.i)}}$		0.002		0.009**		0.003
		(0.001)		(0.004)		(0.003)
Net.Energy.Imports.%	0.0003***	0.0003***	0.001***	0.001***	-0.001***	-0.0002
	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
GDP.Total	-0.000	-0.000	-0.000	-0.000	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Brent.Oil.Price	0.00003	-0.00002	0.0001	0.0002	0.0001	-0.00004
	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Time	-0.00004	0.0005	0.011***	0.008***	-0.003*	0.0003
	(0.001)	(0.0005)	(0.002)	(0.001)	(0.002)	(0.001)
(Country)Australia	0.128	-0.885	-22.227***	-16.445***	5.384*	-0.672
	(1.154)	(0.939)	(3.001)	(2.652)	(3.162)	(2.669)
(Country)Austria	0.125	-0.893	-22.368***	-16.536***	5.526*	-0.609
	(1.159)	(0.941)	(3.011)	(2.658)	(3.174)	(2.673)
(Country)Canada	0.107	-0.906	-22.267***	-16.468***	5.407*	-0.669
	(1.156)	(0.940)	(3.004)	(2.654)	(3.166)	(2.670)
(Country)Germany	0.092	-0.925	-22.250***	-16.433***	5.450*	-0.676
	(1.159)	(0.941)	(3.010)	(2.657)	(3.174)	(2.672)
(Country)Ireland	0.063	-0.957	-22.338***	-16.503***	5.522*	-0.620
	(1.159)	(0.941)	(3.011)	(2.658)	(3.176)	(2.673)
(Country)New Zealand	0.092	-0.923	-22.307***	-16.497***	5.494*	-0.614
	(1.157)	(0.941)	(3.008)	(2.657)	(3.171)	(2.672)
(Country)Spain	0.073	-0.946	-22.301***	-16.459***	5.490*	-0.656
	(1.159)	(0.941)	(3.013)	(2.658)	(3.176)	(2.673)
(Country)UK	0.100	-0.911	-22.270***	-16.462***	5.399*	0.692
	(1.157)	(0.940)	(3.006)	(2.655)	(3.169)	(2.671)
Observations	128	128	128	128	128	128
R2/Adjusted R2	0.942/0.933	0.944/0.935	0.966/0.960	0.961/0.955	0.752/0.714	0.733 /0.692
Residual Std. Error	0.007(df=111)	0.007(df=111)	0.019(df=111)	0.020 (df=111)	0.020(df=111)	0.021 (df=111)
F Statistic	106.427***	110.187***	183.078***	162.539***	19.807***	17.911***
	(df=17;111)	(df=17; 111)	(df=17;111)	(df=17;111)	(df=17;111)	(df=17;111)

Note:*p<0.1; **p<0.05; ***p<0.01; (Standard errors in brackets)

5. Discussion and implications for the new generation of policy mix studies

Our analysis is a first attempt to systematically quantify policy mix design features and characteristics and analyze their effects. We thereby contribute to improving policy mix thinking in both innovation and policy studies. Here we discuss our findings in light of the theoretical debates referenced in Section 2, along the two design features intensity and technology-specificity, and the characteristic balance. In each of these sub-sections we refer to both research questions. We then discuss how our results provoke an agenda for the new generation of research on policy mixes.

Policy mix design feature intensity

The results to our first research question reveal strong differences in levels and dynamics of overall policy mix intensity across countries. Our results underscore the role of general policy design features (see 2.1) also at the mix level opposed to simply counting policies, which is often done when analyzing policy mixes (see e.g., Kivimaa and Kern, 2016). When comparing the lines in Figure 3 (intensity) with the columns in Figure 5 (number of policies), it becomes obvious that policy intensity does not always correlate with the numbers of policy instruments enacted in a policy mix (i.e., the 'policy density'). For instance, when comparing Germany with Australia, we find that the former has a high policy mix intensity and density and the latter only a high density, as symbolic policies are 'discounted' by the IPA approach. Based on our results (also the high explanatory values in the regression model), we argue that measures like policy intensity (which can be applied to policy mixes in any field), should be used in analyzes measuring general policy mix design features (as opposed to stringency – see section 2.1).

Policy mix design feature technology-specificity

With regards to the transitions-related design feature technology-specificity, we also observe large variance between countries (see Figure 3). This can inform the debate around a country's propensity to 'pick winners'. [10] We see that countries with a strong general industry policy tradition (such as Germany and Spain) are more willing to 'pick winners' also in the emerging field renewable energy policy. Their policy mix is characterized by high technology-specificity from the beginning. On the opposite, New Zealand and the UK, both countries that do not have strong industry policy traditions (in the UK at least since the Thatcher government), feature policy mixes with a relatively low technology-specificity.[11] While there is large variance at the intensity on the four technology-specificity levels, the analyzed countries do not seem to favor specific technologies at the technology level, where – with the exception of Ireland – we observe mostly parallel policy intensity in the policy mix for each individual renewable energy technology (see Figure 4). This puts in question the notorious claim that "governments are bad at picking winners" as they pick politically opportune options. This claim would result in one or two technologies scoring much higher than other technologies (i.e., not the mostly parallel curves we observe).

Our results to the second research question highlight the importance of technology-specificity for technology selection. While for biopower and PV the results are in line with our assumption (which was

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[10] Compare the debates on "picking winners" (see Section 2.1) and on varieties of capitalism (Hall and Soskice, 2001).

[11] In the UK, however, technology-specificity is increased incrementally, which may be related to government changes in the majority-based Westminster democracy. The first change we observe coincides with the shift from the Blair to the Brown government, the second coincides with the shift from the Brown to the Cameron government, highlighting the important role of government leadership in the policy-making process.

informed by analyzes of individual policy instruments), the case of wind sticks out: Other than previous studies analyzing the effect of individual (cornerstone) policies, we find that a higher technology-specificity is necessary to induce the diffusion of wind capacity. This finding can inform transitions literature (see e.g., Smith and Raven, 2012): technologies less conform with the incumbent socio-technical regime (such as wind compared to biopower) seem to require additional instruments at the technology-level, to 'stretch' the regime and allow the niche-technology to enter markets. The role of these additional policies is overlooked by studies focusing purely on individual (cornerstone) instruments, such as FiTs or RPS, and not the overall policy mix and its design features. These results indicate that analyzing the policy mix might be more helpful in explaining technology diffusion in comparison to an analytical focus on individual instruments alone.

Policy mix characteristic balance

Regarding the policy mix balance on the technology-specificity levels, we find a rather limited relevance in explaining technology diffusion (compare Section 4.2). Hence, the role of balance does not seem to be of direct importance for technology diffusion. However, our findings point towards an important interrelation between policy mix balance and the 'directionality' (Howlett and Cashore, 2007) of policy change. When comparing instances of significant shifts in policy mix balance (Figure 5) with the further development of policy mix intensity (Figure 3), two distinct patterns are discernable: if marked dips in balance are offset in the short run, intensity continues to increase in the following years or after a short time-lag of 3 to 4 years. For example, the pronounced early dip in balance at the field level in the UK is quickly reversed and the subsequent development of mix intensity is positive. A similar pattern can be found in other countries over the observed time-period and seems to be independent of the technology-specificity level. In contrast, when mix imbalance is not confronted, the subsequent development of mix intensity seems to steer towards stagnation and long-term dismantling. These findings can be interpreted as an indication of the importance of layering as a strategy for policy mix design (compare Section 2.2): The political sustainability of new policy schemes hinges on policy-makers' ability to strengthen support by empowering new actors, deflecting pressure on policy makers from incumbent actors, and by distributing costs and benefits across all relevant actors. This can be achieved by adding new instrument types to the mix. This is an important insight for research analyzing 'policy mix patching' for influencing the long-term directionality of policy change: While this type of 'strategic layering' does not prove relevant in increasing policy mixes' effectiveness (at least in terms of technology diffusion, see above), it seems to be relevant to the 'politics of policy mixes'.[12]

Informing the research agenda for the new generation of policy mix studies

While many past studies of policy mixes have focused on interactions between (a few selected) instruments or conceptually derived characteristics of individual policy mixes in single country or small-

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[12] In addition, this relates to the conceptual discussions in policy studies about gradual paradigmatic modes of policy change (Howlett and Cashore, 2007).

n studies we focus on a larger-n sample and observe the dynamics and effects of mixes over 14 years. The relevance of such analyses has been highlighted before (Howlett and del Rio, 2015), however our study is the first to empirically identify policy mix patterns over such a large sample and time. This very empirically driven approach generates new – both empirical and conceptual – questions for future research on policy mixes. Here we derive three questions from the observed patterns. First, the determinants of the observed differences in policy mix should be analyzed in more detail. Besides established determinants of policy change, such as political institutions, the role of political actors, or policy diffusions across jurisdictions, our results point to the role of industry policy tradition. More abstract 'instrument logics' (Howlett and Cashore, 2009), such as the propensity to 'pick winners' seem to determine design choices in policy mixes in new fields (such as renewable energy policy). A research question is therefore to which extent countries follow higher-level 'policy styles' when establishing new policy fields, and how this determines policy mix trajectories. Also the second question relates to the underlying 'politics of policy mixes'. While past studies have focused on three policy mix characteristics that are related to policy outcome, namely consistency, coherence and congruence (Howlett & Rayner 2007, 2013; Kern & Howlett, 2009; Howlett & del Rio 2015), we introduce a new characteristic: the balance of instrument types.[13] This balance seems to be relevant in explaining subsequent developments of policy mixes. We propose that future research empirically analyzes the role of policy mix balance in more detail and engages in improving our conceptual understanding of policy mix characteristics that are related to subsequent policy output. A third question relates to the design features at the instrument mix tier. Our results highlight the importance of analyzing the entire mix and its design features compared to simply focusing on cornerstone instruments' design features (see the results for wind in research question 2). Future research should thus investigate other *general* design features, such as 'predictability' (compare e.g., Kemp and Pontoglio, 2011), as well as policy-field related design features, such as 'application-specificity' (compare Schmidt et al., 2016) in the case of policy mixes related to technological transitions.

6. Conclusion and limitations

This paper is a first attempt to analyze the evolution and effect of policy mixes in a larger-n study. We thereby aim to increase our understanding of the evolution of actual policy mixes, a precondition for developing meaningful policy design prescriptions (Howlett & del Rio 2015; Flanagan & Uyarra 2016) as well as strategies for 'patching' existing policy mixes (Howlett & Rayner 2013). Besides the empirical contribution of providing an empirical dataset on the long-time dynamics (1998-2014) and effects of policy mixes comprising 522 policies across nine countries, we contribute to the policy mix debate conceptually. First, we conceptualize design features of policy mixes, linking general and innovation-related policy design studies with policy mix literature. We focus on the general design feature of *policy*

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[13] Note that Costantini et al. (2017) also develop an indicator of balance in policy mixes, however, focusing on the balance between technology push and demand pull policies.

intensity and the transitions-related design feature *technology specificity*, providing measurement approaches and empirically analyzing their dynamics and effects. Second, we propose ‘balance’ as a new policy mix characteristic, for which we also propose a measurement approach, and whose dynamics and effects we describe and test empirically. Based on our empirical findings we derive empirical and conceptual questions for future policy mix-related research.

Our paper is of course only a first attempt to conceptualize and measure design features and characteristics of policy mixes over time. As such it is not free of limitations, which should be addressed by future research: First, more countries should be included and the policies extended beyond renewable energy (or energy in general). Second, as technological change does not only refer to technology diffusion but includes innovations as well, other dependent variables (such as patents as proxies for inventions) could be used in order to improve our understanding of the effect of specific design features of policy mixes for transitions. Third, supra- and sub-national policy mixes and their interaction with national policy mixes should be analyzed. Fourth, we focus on one policy field only. Our concepts should also be applied to other policy fields (related to sustainability transitions and beyond).

Despite these limitations, we are confident that our approach can give new momentum to the study of policy mixes in terms of understanding and theorization of the phenomenon and its underlying processes and contribute to the new generation of research on policy mixes. Ultimately, this then can lead to a better understanding of how to nurture policy-making processes that provide opportunities to challenge dominant actors and views, thus enabling technological transition.

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Appendix

Table 1: Correlation table

	%Net Energy Imports	Brent Oil Price	GDP Total	IPA Economy	IPA Sector	IPA Field	IPA Tech - Total	IPA Tech - Biopower	IPA Tech - Wind	IPA Tech - PV	IPA Tech - No Biopower	IPA Tech - No Wind	IPA Tech - No PV
Biopower as % Installed Capacity	0.09	0.11	-0.12	-0.06	0.27	0.51	-0.13	-0.22			0.06		
Wind as % of Installed Capacity	0.45	0.49	0.42	0.23	-0.04	0.21	0.70		0.70			0.56	
PV as % of Installed Capacity	0.11	0.44	0.60	0.26	0.12	0.27	0.68			0.65			0.51
% Net Energy Imports	1.00	0.00	-0.03	-0.04	-0.15	-0.24	0.26	0.45	0.38	0.26	-0.10	0.09	0.19
Brent Oil Price		1.00	0.29	0.39	0.38	0.45	0.58	0.50	0.52	0.52	0.48	0.52	0.47
GDP Total			1.00	0.48	0.23	0.40	0.61	0.53	0.47	0.57	0.49	0.64	0.48
IPA Economy				1.00	0.28	0.12	0.40	0.31	0.40	0.22	0.36	0.31	0.42
IPA Sector					1.00	0.42	-0.01	-0.06	-0.07	-0.03	0.07	0.06	0.02
IPA Field						1.00	0.30	0.07	0.07	0.28	0.50	0.47	0.23
IPA Tech - Total							1.00	0.89	0.90	0.78	0.77	0.89	0.89
IPA Tech - Biopower								1.00			0.39		
IPA Tech - Wind									1.00			0.60	
IPA Tech - PV										1.00			0.40

Table 2: Coding scheme for calculating the Index of Policy Activity (IPA). Adaptation based on Schaffrin et al. (2014, 2015)

Intensity measure	Coding question	Coding values	Specific aggregation to final value	Range
Integration	Is the policy instrument integrated in a package or closely related to other policy instrument(s)? Is a framework policy included?	0=no 0.5=yes 1=yes, including framework policy	additive aggregation	0, 0.5, 1
Scope	Does the policy include branches of both supply and demand side? Are all mitigation actions targeted?	0=only one target group included 0.16=for each target group households/ companies demand/ supply 0.5=all groups targeted 0.15=energy efficiency targeted 0=only one mitigation action targeted 0.05=for each additional action out of oil, gas, coal/CCS, wind, solar, biomass, hydro/ocean, and combined heat and power	additive aggregation	0-1
Objectives	What is the policy objective with respect to policy performance?	0=no specific target given CALCULATION: objective for absolute emission reduction CALCULATION: objective for energy efficiency increase CALCULATION: objective for absolute increase in energy production from renewable sources CALCULATION: objective for absolute decrease in energy production from non-renewable sources *Note:* *Any targets that don't fall into categorization of emissions reduction, renewables or efficiency are coded as 0, as are any targets that are too specific to be meaningfully coded (example: reduce emissions from heavy oil extraction by 80%).* *Energy efficiency targets are coded based on the assumption that 1% efficiency improvement equals 1% reduction in GHG emissions.* *Targets on the reduction of the use of fossil energy can be treated like emission reduction targets under the assumption, that 1% reduction of the use of fossil energy equals 1% reduction in GHG emissions*	We calculate the share of the policy instruments' objective for absolute emission reduction or absolute increase in energy production from renewable energy sources against the benchmark of 80% emission reduction against 1990 levels or 100% energy production from renewable energy sources in 2050. *Note:* *Maximum value for this is assumed to be 1, although calculation allows values >1.* *If multiple targets coded, only the most aggressive one is used for the final value* *For the calculation of the share of energy production from renewable energy it can be assumed that energy production equals energy consumption. If there is no energy data available it can be calculated as the sum of electricity and heat production resp. consumption.*	0-1

Budget	What are the set expenditures/impositions of the policy instrument?	0=no fixed expenditures/impositions CALCULATION: absolute annual expenditure/imposition of policy instrument *Note:* *For multiyear spend, calculated as average of total expenditure over the time period. Funding coming from the revenues from European emissions trading only coded as budget=0.*	We calculate the share of public expenditure or imposition for the policy instrument against total public expenditure for energy and fuels or direct public revenue (in the form of the value added tax). *Note:* *Where both expenditure and imposition are specified, only the higher one is used for the calculation.*	0-1
Implementation	Is there a statement about implementation procedures specifically allocating actors and rules? How is this implementation planned and is there sanctioning?	0=no statement about implementation procedures found 0.25=implementation is specifically allocated to actors and rules 0.25=only one specific actor coordinated implementation 0.25=implementation procedure is strict in the sense that it does not allow a range or change in standards or rules 0.25=there is sanctioning for actors not complying to the implementation procedure	additive aggregation	0-1
Monitoring	Is there a specific monitoring process for the policy instrument and by whom?	0=no monitoring 0.5=monitoring by the implementing agency or other existing agency 1=a special group/institution is established for monitoring	additive aggregation	0-1

Table 3: Description of policy instrument types based on Schaffrin et al. (2014)

Policy type	Description
Education and outreach	Policies designed to increase knowledge, awareness, and training among relevant stakeholders or users, including information campaigns, training programs, labeling schemes.
Incentives and subsidies	Policies to stimulate certain activities, behaviors or investments. These include feed-in tariffs for renewable energy, rebates for the purchase of energy-efficient appliances, grants, and preferential loans and third-party financing.
Financial	Policies to encourage or stimulate certain activities or behaviors. These include tax incentives, such as tax exemptions, reductions or credits on the purchase or installation of certain goods and services.
Framework policy	Refers to the processes undertaken to develop and implement policies. This generally covers strategic planning documents and strategies that guide policy development. It can also include the creation of specific bodies to further policy aims, making strategic modifications, or developing specific programs.
Public investment	Policies guiding investment by public bodies. These include government procurement programs (e.g. requirement to purchase energy efficient equipment and vehicles) and infrastructure investment (e.g. urban planning).
RD&D	Policies and measures for the government to invest directly in or facilitate investment in technology research, development, demonstration and deployment activities.
Regulatory instruments	Covers a wide range of instruments by which a government will oblige actors to undertake specific measures and/or report on specific information. Examples include energy performance standards for appliances, equipment, and buildings; obligations on companies to reduce energy consumption, produce or purchase a certain amount of renewable energy; mandatory energy audits of industrial facilities; requirements to report on GHG emissions or energy use.
Tradable permits	Refers to three kinds of systems – GHG emissions trading schemes, white certificate systems stemming from energy efficiency or energy savings obligations, and green certificate systems based on obligations to produce or purchase renewable energy-sourced power (generally electricity). In GHG trading schemes, industries must hold permits to cover their GHG emissions; if they emit more than the amount of permits they hold, they must purchase permits to make up the shortfall. If they emit less, they may sell these. White certificate schemes create certificates for a certain quantity of energy saved, for example one MWh; regulated entities must submit enough certificates to show they have met energy saving obligations. Again, if they are short, this must be made-up through measures that reduce energy use, or through purchase of certificates. Green certificates refer to renewable energy certificates that represent the certified generation of one unit of renewable energy, generally one megawatt-hour. Certificates can be traded among consumers and/or producers and used to meet renewable energy obligations.
Voluntary agreements	Refers to measures that are undertaking voluntarily by government agencies or industry bodies, based on a formalized agreement. There are incentives and benefits to undertaking the action, but generally few legal penalties in case of non-compliance. The scope of the action tends to be agreed upon in concert with the relevant actors. These are often agreed to between a government and an industry body, with the latter agreeing to certain measures; for example, reporting information on energy use to the government, being subject to audits, and undertaking measures to reduce energy use

Figure 1: Shares of individual renewable technologies as percentage of totally installed capacity (TIC)