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Towards a more comprehensive policy mix conceptualization for environmental technological change: a literature synthesis

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Abstract

Reaching a better understanding of the politics and policies of transitions presents a main agenda item in the emerging field of sustainability transitions. One important requirement for these transitions, such as the move towards a decarbonized energy system, is the redirection and acceleration of technological change, for which policies play a key role. Several studies of policies supporting environmental technological change have argued for the need to combine different policy instruments in so-called policy mixes. However, existing policy mix studies often fall short of reflecting the complexity and dynamics of actual policy mixes, and they lack a common terminology. In this paper we take a first step towards a more comprehensive policy mix concept for environmental technological change based on a review of the bodies of literature on innovation studies, environmental economics and policy analysis. The concept we develop consists of the three building blocks elements, processes and dimensions and introduces a clear terminology, which is particularly important for the characteristics of such a policy mix, including the consistency of its elements and the coherence of its processes. Throughout the paper, we illustrate the concept using the example of the policy mix for fostering the transition of the German energy system to renewable power generation technologies. We argue that the proposed concept provides an interdisciplinary analytical framework for empirical studies analyzing the impact of the policy mix on environmental technological change and may thereby contribute to reaching a better understanding of the politics and policies of sustainability transitions. Finally, we derive policy implications and suggest avenues for future research.

Keywords

Policy mix, policy strategy, instrument mix, policy making and implementation, consistency, coherence

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1 Introduction

One of the main challenges in the emerging field of sustainability transitions is to improve our understanding of the politics and policies of transitions, such as for the move towards a decarbonized energy system (Markard et al., 2012). One important requirement for such a transition is the redirection and acceleration of technological change towards sustainability objectives. However, this environmental technological change, often characterized by its three major stages of invention, innovation and diffusion (del Río González, 2009b, Schumpeter, 1942), is faced with multiple market, system and institutional failures and thus requires multi-faceted policy interventions (Lehmann, 2010, Twomey, 2012, Weber and Rohracher, 2012). Responding to this challenge, in recent years several scholars and practitioners in fields particularly relevant to eco-innovation (Kemp, 2011, Rennings, 2000) have called for a policy mix which combines several policy instruments, including climate policy (IEA, 2011b, Matthes, 2010), environmental policy (OECD, 2007, Ring and Schröter-Schlaack, 2011) and innovation policy (Flanagan et al., 2011, Nauwelaers et al., 2009). However, policy mix studies tend to be limited to examining instrument interactions (del Río González, 2006, IEA, 2011a) or the policy processes associated with designing policy mixes (Howlett and Rayner, 2007). Furthermore, the terminology applied in these studies is often ambiguous, particularly regarding the desired characteristics of a policy mix.[1]

This limited scope and ambiguous terminology of existing policy mix studies have two major consequences. First, the narrow scope of policy mix concepts may cause researchers to neglect important policy mix elements or processes in their analyses of environmental technological change. This may lead to an insufficient understanding of the complex nature of policy mixes and their effects, potentially resulting in fragmentary and oversimplified policy recommendations. Second, the lack of a uniform terminology may render policy mix analyses difficult to assess, compare and synthesize. As a result, policy mix studies

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

may generate ambiguous findings, ultimately reducing the substance and impact of their policy recommendations.

In this study we address the identified lack of a comprehensive, uniformly defined policy mix concept for environmental technological change, thereby heeding Flanagan et al. (2011)'s call for a reconceptualization of the policy mix for innovation. More precisely, we aim to identify and define the key elements and processes of a policy mix and how they can be characterized, and in so doing also consider overarching dimensions. We take a first step towards a more comprehensive policy mix concept for environmental technological change based on a review of the literature on innovation studies, environmental economics, and policy analysis. In addition, where needed we complement our literature survey with contributions from other fields, such as strategic management. Our ultimate objective is the derivation of a policy mix concept that can serve as a starting point and integrating framework for empirical analyses in the field of environmental technological change. Such an analytical framework should enhance our understanding of policy mix effects and thus ultimately enable more precise policy recommendations.

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

The remainder of the paper is structured as follows. In section 2 we review the literature on policy mixes and their characteristics and derive requirements for a more comprehensive policy mix concept. Based on this, in section 3 we present the three building blocks of the proposed policy mix concept: elements (section 3.1), processes (section 3.2) and dimensions (section 3.3), while in section 4 we discuss the most central characteristics of such a policy mix, including consistency (section 4.1) and coherence (section 4.2). Finally, in section 5 we first synthesize the proposed policy mix concept (section 5.1) and then illustrate this analytical framework using the example of the German Energiewende (section 5.2). Section 6 derives policy implications and concludes the paper.

2 Literature review

2.1 Policy mix

A growing number of studies in various scientific fields use the term *policy mix*, e.g. Lehmann (2010) in environmental economics, Nauwelaers et al. (2009) and de Heide (2011) in innovation studies, and Howlett and Rayner (2007) in the field of policy analysis.[2] In its most basic form, studies implicitly or explicitly define a policy mix as the combination of several policy instruments (Lehmann, 2012, Matthes, 2010).[3] However, as stressed by Flanagan et al. (2011), a policy mix encompasses more than just a combination of policy instruments; it also includes the processes by which such instruments emerge and interact. As a consequence, studies focusing solely on the combination of instruments should, more precisely, refer to the term 'instrument mix' (see section 3.1.3).[4] Table 1 gives an overview of some policy mix definitions, with the more elaborate ones mainly originating from innovation studies and the policy analysis literature.

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

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

3 Some studies also use the term 'policy mix' interchangeably with 'instrument mix' (e.g. Ring, Schröter-Schlaack (2011)).

4 This is done, for example, by OECD (2007), Braathen (2007) and Murphy et al. (2012). Similarly, Borrás and Edquist (2013) argue for a distinction between instrument mix and policy mix (see footnote 6).

their meanings may change over time, causing interactions between them to change (IEA, 2011b, Sorrell et al., 2003).

Table 1: Definitions of the term *policy mix* in the literature

Source	Definition
Guy et al. (2009) (p.1)	"An R&D and Innovation Policy Mix can be defined as that set of government policies which, by design or fortune, has direct or indirect impacts on the development of an R&D and innovation system."
Kern and Howlett (2009) (p.395)	"Policy mixes are complex arrangements of multiple goals and means which, in many cases, have developed incrementally over many years."
Nauwelaers et al. (2009) (p.3)	"A policy mix is defined as: The combination of policy instruments, which interact to influence the quantity and quality of R&D investments in public and private sectors."
Boekholt (2010) (p.353)	"A policy mix can be defined as the combination of policy instruments, which interact to influence the quantity and quality of R&D investments in public and private sectors."
De Heide (2011) (p.2)	"A policy mix is the combined set of interacting policy instruments of a country addressing R&D and innovation."
Ring and Schröter-Schlaack (2011) (p.15)	"A policy mix is a combination of policy instruments which has evolved to influence the quantity and quality of biodiversity conservation and ecosystem service provision in public and private sectors."

Yet, a comprehensive policy mix concept needs to go beyond this narrow scope – interacting instruments aimed at achieving objectives in a dynamic setting – at least in three respects. First, aside from capturing its dynamic nature, a comprehensive concept of the policy mix should consider more of its *complexity*, thereby going beyond combinations of policy instruments and their interactions (Flanagan et al., 2011). Second, it needs to more explicitly incorporate *policy processes* "by which policies emerge, interact and have effects" (Flanagan et al. (2011), p.702) since such processes help explain the evolution and effects of policy mixes, as discussed, for example, by Foxon and Pearson (2007, 2008) for the case of innovation in renewable power generation technologies. Third, a comprehensive policy mix concept ought to include a *strategic component*. This tends to be neglected despite early works of Jänicke on the role of strategic approaches in environmental policy (Jänicke, 1998, Jänicke, 2009), the necessity of long time horizons for sustainability transitions (Markard et al., 2012) and recent empirical evidence on the importance of long-term climate targets for companies' innovation strategies (Rogge et al., 2011a, 2011b, Schmidt et al., 2012b).

2.2 Characteristics of policy mixes

The literature uses a number of terms to describe the desired nature of a policy mix. These can be classified in two main groups: policy mix characteristics and assessment criteria (OECD, 2003a, Sorrell et al., 2003). Terms belonging to the latter group represent well-established ex-ante and ex-post assessment criteria applied in impact assessments and evaluations of single policy instruments, such as effectiveness, efficiency, equity or feasibility (del Rio et al., 2012, IRENA, 2012). In contrast, the former group comprises terms specifically used for characterizing the policy mix, such as consistency, coherence, credibility, stability or comprehensiveness (Foxon and Pearson, 2008, Howlett and Rayner, 2007, Kern and Howlett, 2009, Majone, 1997, Matthes, 2010). These often ambiguously defined characteristics may impact the performance of a policy mix in terms of the standard assessment criteria, particularly regarding effectiveness and (dynamic) efficiency. However, most policy mix studies refer to these characteristics without clarifying which of the various definitions they are applying, thus rendering it difficult to assess what is actually meant. This is particularly problematic for the frequently used terms *consistency* and *coherence* with their great heterogeneity of definitions (Den Hertog and Stroß, 2011e, Picciotto, 2005).[5] Thus, we focus on a review of the – predominantly policy analysis – literature on these terms. Based on this we identify three important points to be taken into account when establishing a more uniform terminology.

First, consistency and coherence are either seen as *identical or different characteristics*. The former suggests coherence is synonymous with consistency (Carbone, 2008, Hoebink, 2004, Matthews, 2011). As a result, coherence is often simply defined using the term consistency (Hydén, 1999, Picciotto et al., 2004), but there is no uniform definition. [6] In contrast, the latter distinguishes

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5 For an overview of definitions of consistency and coherence, see Table 12 in the annex. Also, Weston and Pierre-Antoine (Weston and Pierre-Antoine, 2003) provide a historical account of the relevance of policy coherence for development policies.

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

consistency and coherence as different characteristics (Howlett and Rayner, 2007, Mickwitz et al., 2009a, OECD, 2001), but again there is no agreement on the exact nature of this difference. However, the majority of these studies assert that coherence is more encompassing than consistency (Jones, 2002, OECD, 2003a). That is, in its most basic form, consistency is seen as the absence of contradictions (Den Hertog and Stroß, 2011d, Gauttier, 2004), while coherence calls for an achievement of synergy or positive connections (Missiroli, 2001, Tietje, 1997).[7]

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

Third, another key point is the focus on *tools* for enhancing consistency and coherence (Ashoff, 2005, OECD, 1996, OECD, 2003a), a discussion which is closely linked to the literature on policy coordination[8] and integration[9] (Mickwitz et al., 2009a, Van Bommel and Kuindersma, 2008b). However, as before, there is no common understanding of the terms consistency and coherence and how they relate to other concepts, such as coordination. One reason for this lack of a uniform terminology may be the often largely separated contributions addressing distinct policy fields, such as development policy (EU, 2005, 2010), climate

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

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

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

policy (Kern and Howlett, 2009, Mickwitz et al., 2009b) and eco-innovation policy (Reid and Miedzinski, 2008, Ruud and Larsen, 2004).

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

3 Building blocks of the policy mix concept

As derived in the literature review, a more comprehensive policy mix concept needs to address three basic requirements: first, the consideration of the *complex and dynamic nature* of policy mixes, second, the incorporation of associated *policy processes*, and third, the inclusion of a *strategic component*. Also, to resolve concerns over ambiguous terminology, it needs to suggest precise definitions of key terms.

Based on these requirements, we define the *policy mix* as a combination of the three building blocks elements, processes and dimensions. *Elements* comprise the policy strategy with its objectives and principal plans for achieving them as well as the instrument mix with its interacting policy instruments. These elements are shaped by the *processes* of policy making and implementation. Both elements and processes can be specified by their *dimensions*, including policy field, governance level, geography, sector, technology, innovation, actor and time. This complex and dynamic policy mix can be described by its characteristics, including consistency of its elements and coherence of its processes. In the following, we introduce the three building blocks of the policy mix concept.

3.1 Elements

3.1.1 Policy strategy

The importance of a long-term strategic orientation and strategic policy frameworks has been increasingly underscored in the literature addressing sustainability transitions (Foxon and Pearson, 2008, Quitzow, 2011, Weber and

Rohracher, 2012) and policy-triggered environmental technological change (Rogge et al., 2011b, Schmidt et al., 2012b). We therefore incorporate policy strategy as one of the elements in the comprehensive policy mix concept. However, given the conceptual underdevelopment of policy strategy, we draw on the strategic management literature to derive a common definition of it (see Table 6 in the annex). This literature highlights that strategy consists of a combination of interdependent ends (goals) and means (policies) to achieve the ends (Andrews, 1987, Miles and Snow, 1978, Mintzberg, 1999, Porter, 1980).

Building on Andrews (1987) and Porter (1980), we thus define policy strategy as a combination of policy objectives and the principal plans for achieving them. That is, the definition puts an emphasis on the output of the strategy process – the ends and means – rather than the process of formulating and implementing objectives and plans (see section 3.2.1). We will discuss these two main components in turn, while recognizing that they are closely interlinked.

The first component of the policy strategy definition concerns *policy objectives* associated with sustainability transitions. These objectives tend to be substantiated by long-term *targets* with quantified ambition levels (Rennings et al., 2003, Schmidt et al., 2012b) and may be based on visions of the future (del Río et al., 2010, Kemp and Rotmans, 2005).[10] [11] For example, one of the policy objectives of the EU is the reduction of greenhouse gas (GHG) emissions. This is concretized by a 20% GHG reduction target for 2020 compared to 1990, with negotiations underway for updating this to 2030, aiming at arriving at numbers in line with the internationally agreed target of 2°C (EU, 2013).[12] In addition to environmental objectives, the policy strategy may also include social and economic issues (Daly and Farley, 2010), such as the support of growth, competitiveness and jobs (EU, 2013). Besides content-oriented objectives, a policy

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

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

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

strategy can also contain process and learning objectives, which may be particularly relevant in the context of sustainability transitions (Kemp, 2007, Rotmans et al., 2001).

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

The long-term perspective inherent in the policy strategy (Hillman and Hitt, 1999) can play a fundamental role in providing actors with needed guidance in their search and can thus support one of the functions of innovation systems (Hekkert et al., 2007). For example, research has shown the vital role of long-term climate targets in steering R&D activities of companies in the power sector (Rogge et al., 2011a, 2011b, Schmidt et al., 2012b). However, the same research has also pointed out that this strategic element of the policy mix on its own is not sufficient to change companies' innovation strategies but needs to be operationalized through concrete policy instruments. These are addressed in the next section.

3.1.2 Instruments

As the second element in the policy mix, policy instruments constitute the concrete tools to achieve overarching objectives. More precisely, they can be seen as tools (Salamon, 2002) or techniques of governance (Howlett, 2005) that address policy problems (Pal, 2006). They are realized with the active involvement of the public sector (Nauwelaers et al., 2009) or, more specifically, are introduced by a governing body (Sorrell et al., 2003) in order to achieve policy objectives (Howlett and Rayner, 2007), thereby translating plans of action (de Heide, 2011).[13] Examples of policy instruments include the German feed-in tariffs incorporated in the Renewable Energy Act (EEG), the KfW Program Renewable Energies and the EU ETS.

13 For further definitions of policy instruments, see Table 7 in the annex.

In addition to the term ‘instrument’, studies of policy instruments also speak of implementing measures (EU, 2013), programs (Komor and Bazilian, 2005), policies (Fischer and Preonas, 2010, IRENA, 2012), or policies and measures (UNFCCC, 2011). For simplicity, we use the term ’instrument’ in the policy mix concept, with the clear understanding that it encompasses these alternative terms. However, as the term ‘policy’ is very broad, we prefer not to use it synonymously for ‘instrument.’[14]

Policy instruments are typically associated with specific goals.[15] That is, while the policy strategy contains objectives which tend to be specified by long-term targets, we use the term ‘goal’ to characterize the intended effect of instruments that contribute to achieving overarching policy objectives. In addition, two key characteristics of policy instruments are particularly relevant for innovation, namely instrument *type* (section 3.1.2.1) and instrument *design feature* (section 3.1.2.2).

3.1.2.1 Instrument type

The type of an instrument has been identified as a major determinant of environmental policy instruments’ impact on innovation, both in theoretical (Jaffe et al., 2002, Popp et al., 2009, Requate, 2005) and empirical studies in environmental economics (Hašcic et al., 2009, Hemmelskamp, 1999b, Johnstone et al., 2010). However, in the context of environmental technological change, the policy mix concept needs to incorporate not only environmental instrument types but at a minimum innovation instrument types as well. However, no uniform instrument typology exists in either policy field (Hufnagl, 2010).[16] In addition, first attempts at a combined typology (see Table 8 in the annex) tend to lack either a differentiated set of innovation policy types (Rennings et al., 2008)[17] or environmental policy types (Nauwelaers et al., 2009).

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14 For example, Dye (2008, p. 1) defines public policy as “whatever governments choose to do or not to do [..] public policies may regulate behavior, organize bureaucracies, distribute benefits, or extract taxes – or all these things at once.”

15 Some authors refer to such an association of instruments and goals as “policy” (May, 2003, Pal, 2006).

16 For an overview of key instrument type classifications within the scientific disciplines of environmental economics, innovation studies and policy analysis, see Table 13 in the annex.

17 One exception is del Río (2009b).

As a first step towards a more balanced typology, we identified frequent typologies in the environmental and innovation domains (see Table 2). While in the environmental domain both simple and differentiated typology are rather well-established instrument classifications, for the innovation domain this is only the case for the simple typology of technology push vs. demand pull. By contrast, more differentiated innovation policy typologies vary greatly (Hufnagl, 2010), which makes it more difficult to distill recurring instrument types from them.[18]

Table 2: Frequent typologies in the environmental and innovation policy domain

	Simple typology	Differentiated typology
Environmental domain	• Market-/ price-based / economic • Regulation / command-and-control	• Market-/ price-based / economic • Regulation / command-and-control • Information & education • Voluntary approaches
Innovation domain	• Supply-side measures/ technology push • Demand-side measures/ demand pull	• Financial support • Public procurement • Stimulation of cooperation and networks • Provision of public goods • Provision of property rights

Source: Own compilation (based on typologies by Dasgupta and Maskin, 1987, Gunningham and Young, 1997, Hemmelskamp, 1999b, IEA, 2011b, Jordan et al., 2003, Rammer, 2009, Sorrell et al., 2003, Sterner, 2000, Taylor, 2008)

Based on these generic typologies, we propose a matrix typology (see Table 3) that combines three instrument types (inspired by the environmental domain) with three instrument purposes (inspired by the innovation domain). Specifically, the three *instrument types* are economic instruments, regulation and information, the last including education and cooperation (rows in Table 3). The primary *instrument purposes* differentiate between technology push, demand pull and systemic concerns (columns in Table 3), with the last referring to "instruments that support functions operating at system level" (Smits and Kuhlmann,

[18] Due to their cross-cutting character we do not include the so-called 'systemic instruments' in the differentiated typology in Table 2 (Smits and Kuhlmann, 2004, Wieczorek and Hekkert, 2012).

2004, p. 25).[19] Since this 3x3 matrix is an oversimplification of reality, and as such not free of overlaps,[20] we qualify both instrument purpose and type with the word ‘primary’. For each of the nine possible type-purpose-combinations, Table 3 includes some selected examples of instruments relevant to environmental technological change.

Table 3: Type-purpose instrument typology (with selected instrument examples)

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

* RD&D = Research, development and demonstration

Source: Own elaboration (based on del Río González, 2009a, Edler and Georghiou, 2007, Hemmelskamp, 1999b, IEA, 2011b, Mowery, 1995, Rammer, 2009, Rennings et al., 2008, Smits and Kuhlmann, 2004, Sterner, 2000, Wieczorek and Hekkert, 2012)

3.1.2.2 Instrument design features

In the environmental economics literature it has been increasingly pointed out that a policy instrument's design features may actually be more influential for innovation than the instrument type (Kemp and Pontoglio, 2011, Vollebergh, 2007).[21] Therefore, an increasing number of studies explicitly consider them

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

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

21 See Table 11 in the annex for policy instrument design features in the literature.

when analyzing policy instruments and their innovation effects (Ashford et al., 1985, Blazejczak et al., 1999, Norberg-Bohm, 1999). In addition, design features may also impact an instrument's effectiveness and efficiency and are a prerequisite for interaction analyses (del Río González, 2009a).

Design features can be differentiated by abstract and descriptive features. *Descriptive design features*, such as an instrument's legal form[22], its target actors, and its duration, summarize the content of a policy instrument (del Río, 2012), which can serve as a first step in identifying how a policy instrument performs regarding abstract design features. A number of *abstract design features* have been proposed in the literature (Hašcic et al., 2009, Kemp and Pontoglio, 2011)[23], but there is no universally accepted list. In the context of environmental technological change, we argue that at least the following six may be important to consider: stringency, level of support, predictability, flexibility, differentiation and depth.

First, *stringency* addresses the ambition level of an instrument and is typically associated with regulatory and economic instruments, such as emissions standards or emissions trading. It can refer both to an instrument's goal and its design, with the individually perceived stringency ultimately determined by the characteristics of the instrument's target actor, such as its technology portfolio (Rogge, 2010).[24] Although definitions and operationalizations of stringency vary across studies,[25] findings point to a positive impact of stringency on innovation (Ashford et al., 1985, Frondel et al., 2007, Rogge et al., 2011b, 2011c, Schmidt et al., 2012b).

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

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

24 For example, in the EU ETS, the cap sets the limit on overall emissions with straightforward repercussions for the price of allowances. In addition, the mode of allocating allowances also contributes to the firm-level stringency of the trading scheme, depending on a firm's technology portfolio and thus its exposure to the instrument (Rogge, 2010).

25 Definitions range from a focus on the ambitiousness of the instrument goal relative to the baseline trajectory (Hašcic et al., 2009) to a concentration on necessary firm-level monetary efforts for complying with the requirements of a policy instrument (e.g. Bernauer et al., 2006).

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

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

Fourth, *flexibility* captures the extent to which innovators are allowed to freely choose their preferred way of achieving compliance with an instrument (Kivimaa and Mickwitz, 2006, Norberg-Bohm, 1999). Johnstone and Hašcic (2009, p. 1) find that for "a given level of policy stringency, countries with more flexible environmental policies are more likely to generate innovations which are diffused widely and are more likely to benefit from innovations generated elsewhere". A prime example in this regard is the EU ETS which allows firms to freely choose between various compliance options, such as implementing emission reduction measures of existing plants, switching to renewable power generation technologies or purchasing EU allowances.

A fifth abstract design feature concerns the *differentiation* specified in policy instruments (Kemp and Pontoglio, 2011), e.g. with regard to industrial sector, size of the plant, technology or geographical location.[26] Sixth, the *depth* of the policy instrument, addresses the range of its innovation incentives, that is whether its incentives extend all the way to potential solutions with zero emissions (Hašcic et al., 2009).

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

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

3.1.3 Instrument mix

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

The instrument mix is characterized by the *interactions* between the instruments, which signify "that the influence of one policy instrument is modified by the co-existence of other [instruments]" (Nauwelaers et al., 2009, p.4). This influence originates from the effect that the operation of one instrument has on the operation or outcomes of another either directly or indirectly (Oikonomou and Jepma, 2008, Sorrell et al., 2003).[27] Clearly, these interdependencies of instruments largely influence the combined effect of the instrument mix and thus the achievement of policy objectives (Flanagan et al., 2011). It is for this reason that interactions of policy instruments represent a central constituent of any policy mix concept.

Understanding the mechanisms and consequences of policy interactions requires considering a number of aspects, including the scope of the interacting instruments, the nature of their goals, their timing, and operation and implementation processes (Sorrell et al., 2003), suggesting that interaction outcomes are not only determined by the instrument mix but also shaped by the overarching policy mix.

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27 See Tables 9 and 10 in the annex for definitions of interaction types and outcomes.

Naturally, the desired outcome is a positive or complementary effect, for example the interaction of information instruments with most other instrument types (Sorrell et al., 2003). Yet, perhaps more often, negative or incompatible outcomes can be observed (Sorrell et al., 2003). However, as pointed out by Gunningham and Grabosky (1998), without considering the particular context in which interactions occur, only tentative conclusions on their interactions can be reached, thus calling for empirical analyses.

Thus far, interactions have been predominantly dealt with in the environmental domain, particularly on climate and energy issues (del Río González, 2009a, Gunningham and Grabosky, 1998, Sorrell et al., 2003). More recently, innovation studies have also started to highlight interactions (Flanagan et al., 2011, Nauwelaers et al., 2009). All of these studies recognize the importance of interactions among instruments as central to dealing with policy mixes. They also acknowledge the need to avoid negative interactions. In contrast, the policy analysis literature does not usually employ the term ’interaction’ but instead refers to ‘consistency’ and ‘coherence’ when addressing the interrelationships between different instruments.

3.2 Processes

3.2.1 Policy making & implementation

Our conceptualization of the policy mix has thus far focused on describing its elements at a given point in time. These elements are shaped by policy processes, which, due to their importance, constitute one building block of the proposed policy mix concept (Howlett and Rayner, 2007, Kay, 2006). That is, rather than looking only at the content of the policy strategy and instrument mix with its interacting instruments, we now turn our attention to the policy making process, or *policy process* for short (Dunn, 2004, Dye, 2008). Ultimately, it is these processes that determine the elements of the policy mix in the way they proceed and through their outputs (Majone, 1976).

By policy processes we mean “the procedures and institutional arrangements that shape policy making” (Nilsson et al., 2012, figure 1). They cover all stages of the policy cycle, including problem identification, agenda setting, policy formulation, legitimization and adoption, implementation, evaluation or assessment, policy adaptation, succession and termination (Dunn, 2004, Dye, 2008, Schubert and Bandelow, 2009). Because of the fundamental importance of policy implementation in determining the effectiveness and efficiency of a policy instrument, we follow others in differentiating policy processes into policy making and policy implementation (Richardson, 1982).

Regarding *policy making*, we stress two aspects: First, due to the dynamic, multifaceted and uncertain nature of environmental technological change and sustainability transitions, policy adaptation and thus policy learning ought to feature prominently within policy making processes (Allen et al., 2011, Bennett and Howlett, 1992, Kemp et al., 2007, Loorbach, 2007). This includes strengthening the systemic capabilities of policy makers (Jacobsson and Bergek, 2011). Second, in the context of environmental technological change and sustainability transitions, policy making will typically be faced with resistance to change, particularly from actors with vested interests, rendering it more difficult to radically adjust the instrument mix even if new policy objectives are in place. This may be one reason why new instruments supporting niches may be added to those supporting existing regimes instead of replacing them (Kern and Howlett, 2009).

By *policy implementation* we mean "the arrangements by authorities and other actors for putting policy instruments into action" (Nilsson et al., 2012, figure 1), that is, for executing and enforcing them (Sabatier and Mazmanian, 1981). Complex and insufficient implementation structures may lead to implementation difficulties such that ultimately a policy instrument does not tap its full potential. For example, for selected renewable power generation technologies, Reichardt et al. (2011) recommend that particularly in early phases of technology development, policy makers and administrators should collaborate with innovators in order to ensure a smooth functioning of policy implementation. Such difficulties may be overcome by an appropriate crafting of policies (May, 2003, Mazmanian and Sabatier, 1981), including the provision of sufficient funding and staff for implementation, thereby illustrating the close link between policy making and policy implementation.

Policy processes tend to be highly complex with a plethora of involved actors and their interests. For illustrative purposes we present key steps in the evolution of the German policy mix for renewable power generation technologies up to 2004 (see Table 4). These policy making processes range from the promotion of initial support programs by advocacy groups and the parliament to the adoption and first amendments of the German Renewable Energy Act (EEG).

Table 4: Selected policy processes describing the evolution of the German policy mix for renewables (until 2004)

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

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

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

3.3 Dimensions

The discussion thus far has not explicitly considered the complex and dynamic nature of the policy mix. This broader perspective is taken up by the third building block of the policy mix concept: the dimensions in which the policy mix can play out, both in terms of its elements and processes. Relevant dimensions may include, but need not be limited to, the policy field, governance level, geography, sector, technology, value chain position, innovation phase, actor and time. These can serve as a starting point for setting the system boundaries by determining the key dimensions to be considered for each of the elements and processes of a policy mix, as illustrated by Table 5 for the example of renewables in Germany. In the following we briefly introduce each of the nine dimensions of the policy mix.

Table 5: Some choices for setting the boundaries of the policy mix for renewables in Germany

Dimension	**Application to policy mix for renewables in Germany**
Policy field	Climate, energy, innovation, environment, industrial and others
Geography	Germany, regions
Governance level	EU, national, regional, local; departments, implementing agencies
Sector	Power
Technology	Renewable power generation technologies, e.g. wind, PV; competing against established fossil and nuclear power generation technologies
Innovation phase	Invention, innovation, diffusion; or other typologies
Actor	Policy makers (e.g. EU commission, German government) target actors (e.g. private investors, grid operators, households)
Value chain position	Manufacturing, project development, installation, power generation operation & maintenance
Time	Static (e.g. 2009), dynamic (e.g. 1991 to today)

The first dimension *policy field* refers to the policy domain, such as energy, environmental, climate, innovation, technology, science, industrial and transition policy (van den Bergh et al., 2007). For instance, a policy strategy aiming at the promotion of renewable power generation technologies does not have to originate from the field of climate or energy policy but instead could be based on a mix thereof or on industrial policy only, e.g. depending on the national circumstances. Also, the instruments in an instrument mix can typically be attributed to one primary policy field, such as the EU ETS to climate policy. The same may hold for policy making and implementation processes, keeping in mind though that a transition to renewables typically involves more than one policy field.

For the second dimension *governance level* we focus on the distinction between vertical and horizontal, a distinction typically made in studies on policy coherence and consistency (Carbone, 2008, Den Hertog and Stroß, 2011b, den Hertog et al., 2004, Duraiappah, 2004, Pal, 2006). The vertical level differentiates between the EU and the member states as well as between a regional and international level. It further distinguishes between government departments and implementing agencies. For example, in the first and second EU ETS trading phase, policy making has occurred both at the level of the EU and the member states, while its implementation has predominantly taken place at the member state level. In contrast, the horizontal level allows for differentiating between different political or administrative entities at the same vertical governance level, such as federal departments of different policy fields. An example is the German Energiewende, in which six federal departments are involved[28].

Third, closely related to this abstract space of governance level is the *geography* dimension, constituting the space in which the policy mix plays out. This implies a focus on the place where the impact of a policy mix is intended and felt and underlines the increasing attention to the geographical perspective in transition studies (Coenen et al., 2012, Raven et al., 2012, Späth and Rohracher, 2012). An example of this is policy instruments targeted towards a certain geographical region, such as a funding initiative for the deployment of renewable power generation technologies in a specific community.

The fourth and fifth dimensions of the policy mix are the *sector* and the *technology.* They allow, for example, delineating policy mixes within sectoral or technological innovation systems (Hekkert et al., 2007, Malerba, 2004), such as the policy mix relevant for the technological innovation system for PV. In addition, a policy instrument can target and affect specific sectors or technologies. An example of the former is the EU ETS, which initially covered larger installations within the energy and industry sectors only, while an example of the latter is the European Energy Programme for Recovery (EEPR), which only addresses selected low-carbon power generation technologies.

Sixth, closely related to the technology dimension is the dimension of *innovation phase*, as technologies run through various – not necessarily linear – innovation phases, a simple example being the distinction between invention, innovation and diffusion (Schumpeter, 1942). More sophisticated typologies differentiate, for example, between invention, euphoria, disillusionment, reorientation and rise (Jochem, 2009) or between R&D, prototypes, demonstration, pre-commercial and early commercial (niche) technologies to mature technologies, with early adoptions potentially followed by mass application (regime technologies) (Ekins, 2010, Foxon et al., 2005). These differences in the innovation phase may be reflected in the functioning of the corresponding technological innovation systems, calling for an adjustment of policy mixes based on changing needs (Foxon et al., 2005). For example, Rogge et al. (2011a) find that for invention

28 These are the departments of economy, environment, education, transport & buildings, finance, food and agriculture.

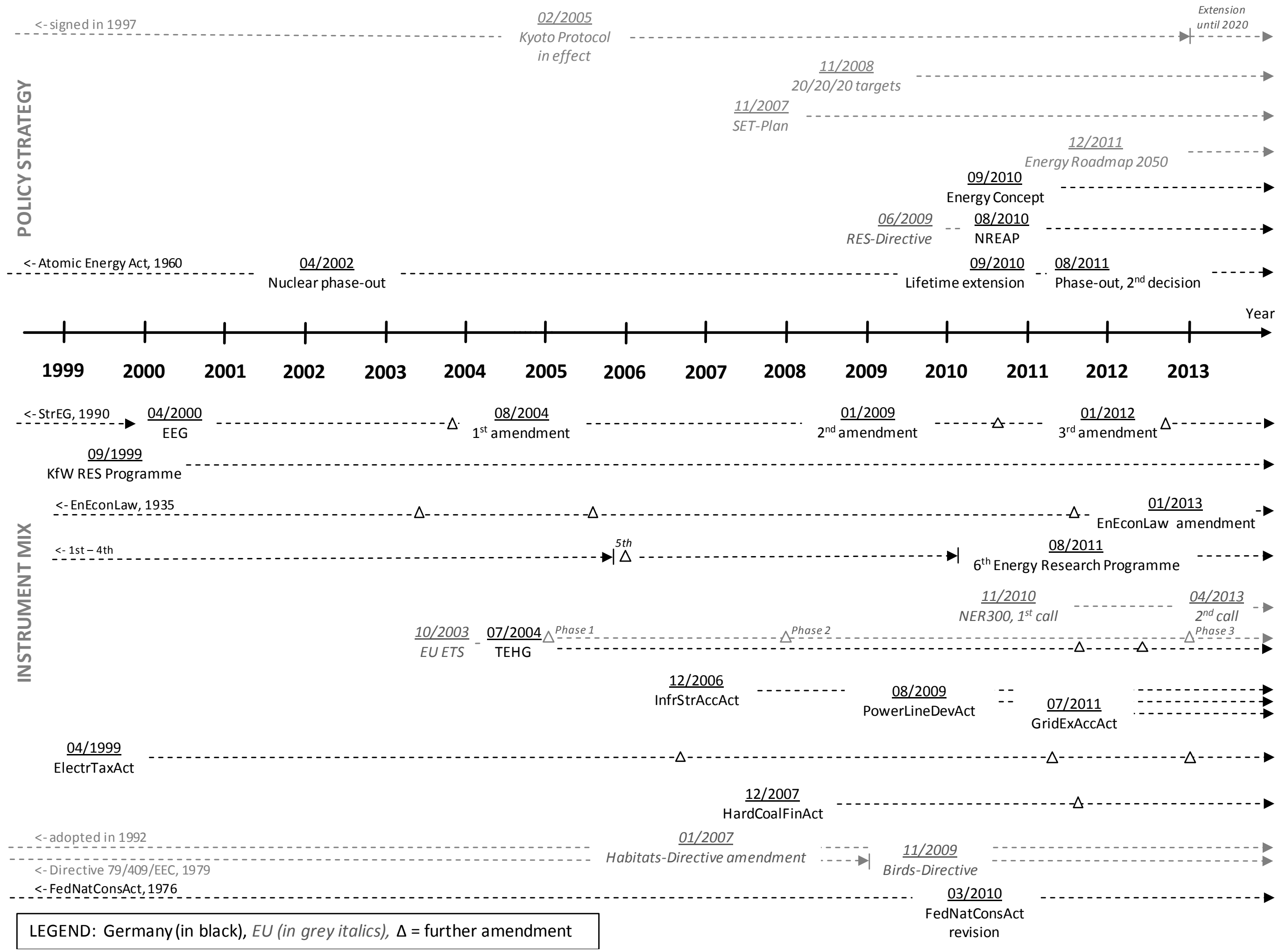
and innovation, firms in the power sector assign a higher relevance to long-term climate targets, while for diffusion the EU ETS plays a greater role.

Seventh, an essential dimension for studying the evolution and effects of policy mixes is the *actor*, that is, the decision-making entities and their behavior, such as authorities, companies, non-governmental organizations and individuals. It is especially helpful to distinguish between actors involved in policy making and implementation, on the one hand, and target actors, i.e. those affected by the resulting policy mix, on the other (Mickwitz, 2003), although the latter may also be involved in policy making, for example through interest groups. The diversity of these target actors may justify tailoring a policy mix to better address this heterogeneity (Schmidt et al., 2012a).

Eighth, the *value chain position* indicates the location of a firm within the market (Cox and Lamming, 1997) and captures "the physically and technologically distinct activities a firm performs" to create a product (Porter, 1985, p. 33). For example, the location of a firm within such a value chain was shown to be important for explaining innovation effects of the policy mix in the power sector, e.g. by identifying trickle down effects of the EU ETS (Rogge et al., 2011b, Schmidt et al., 2012b). Finally, a key link exists between this dimension and the technology dimension, as value chains typically differ across technologies.

Finally, *time* is another crucial dimension in the policy mix concept, capturing its dynamic nature both in terms of its elements and processes. That is, first, all elements of the policy mix change over time, which we illustrate using the example of the evolution of the elements of the German policy mix for renewables from 2000-2013. As can be seen in Figure 2 both the policy strategy and the instrument mix have changed over the years, with new elements added and existing ones amended or terminated. However, the policy strategy and policy instruments may not only change in terms of their contents, ideally resulting in continuous improvement (Kivimaa, 2007), but also in terms of their effects as they are interpreted against changing rationales (Flanagan et al., 2011). Similarly and resulting from changing instruments, interactions are also not stable over time, which may cause the instrument mix to drift out of alignment (IEA, 2011b, Sorrell et al., 2003). Second, policy processes may also change over time (Flanagan et al., 2011). They should be characterized by adaptive policy making to allow for adjusting the policy mix as "the world changes and new information becomes available" (Walker et al., 2001, p.283). This key requirement has been

Figure 1: Development of the elements of the policy mix for renewables in Germany over time[29]



29 See Figure 4 in the annex for an explanation of the depicted elements of the policy mix (policy strategy and instrument mix).

recognized in the literature on policy learning, e.g. in the context of transition management (Loorbach, 2007, Rotmans et al., 2001).

4 Characteristics of a policy mix

We now turn to the characteristics of a policy mix, which can be applied both to the overarching policy mix and to distinct elements or processes. We start with consistency (section 4.1), proceed to coherence (section 4.2), and end by presenting some additional key characteristics such as credibility (section 4.3).

4.1 Consistency of elements

Building upon the literature review in section 2.2, we propose characterizing the elements of the policy mix with the term *consistency*. That is, we suggest that consistency refer to the state of a policy mix that is characterized in its weak form by the absence of contradictions and in its strong form by the existence of synergies within and between the elements of the policy mix, thereby enabling the achievement of policy objectives. As such, the consistency of the policy mix encompasses three levels: (1) consistency of the policy strategy, (2) consistency of the instrument mix as determined by the nature of its interactions, and (3) consistency of the instrument mix with the policy strategy.

We highlight three key features of this consistency definition. First, it focuses on the *state of the elements* of the policy mix at any given point in time, i.e. we explicitly exclude the process perspective (for this, see section 4.2). Of course, the consistency of the policy mix can be captured dynamically by measuring it over time (see section 3.3 on dimensions). Second, we differentiate between *weak and strong consistency*. By weak consistency we mean that at a minimum, a consistent policy mix needs to be free of contradictions or conflicts within or between its elements (Forster and Stokke, 1999) so that these do not impair the achievement of policy mix objectives (Ashoff, 2005, Hoebink, 2004, McLean Hilker, 2004). In contrast, strong consistency refers to complementarities, mutual support and synergies between and within the elements of the policy mix. Third, we envisage *three main levels of policy mix consistency*.

We choose the first level of policy mix consistency to address the *policy strategy*, since conflicting objectives are a major source of tension between the instruments in a policy mix (Flanagan et al., 2011). Consistency of the policy strategy comprises three sub-levels. First, objectives ought to be consistent

(Mickwitz et al., 2009a, OECD, 2003a), suggesting that they can be achieved simultaneously without any significant trade-offs. Examples are whether climate targets are consistent with targets for the penetration of renewables or energy efficiency targets, or whether interim targets are consistent with long-term targets. Second, principal plans, i.e. framework conventions, guidelines, strategic action plans and roadmaps, ought to be consistent. For example, the German National Renewable Energy Action Plan (NREAP) can be seen as relatively consistent with the EU Strategic Energy Technology (SET) Plan, since both envisage the increased development and diffusion of renewables. Third, principal plans should be consistent with policy objectives. An example of this is the German Energy Concept's (2010) confirmation of the German 40% GHG emissions reduction target by 2020 as originally specified in 2002.

The second level concerns consistency of the *instrument mix*[30], which can be assessed through interaction analysis. The instruments in an instrument mix are "consistent when they work together to support a policy goal. They are inconsistent when they work against each other and are counterproductive" (Kern and Howlett, 2009, p.396). Therefore, strong instrument mix consistency is associated with positive interactions, weak instrument mix consistency is characterized by neutral interactions, while instrument mix inconsistency is captured by negative interactions (del Río González, 2009a, del Río González, 2010, IEA, 2011b, Sorrell et al., 2003). However, this link between consistency and interaction is rarely addressed in the literature.[31]

The ultimate test of policy mix consistency is found at the third level, the *interplay of the instrument mix and the policy strategy*. First and second-level consistency are necessary but not sufficient conditions for third-level consistency. This overall policy mix consistency necessitates a conflict-free, ideally synergy-creating alignment of a consistent policy strategy and a consistent instrument mix, thereby ensuring that objectives can be achieved.[32] That is, the strategy needs to be implemented using instruments capable of reaching the objectives. For example, the instrument mix operationalizing the German Energiewende is currently sometimes perceived as inconsistent with its ambitious targets, which

30 Instrument mix consistency includes the internal consistency of a single policy instrument, i.e. the consistency of the instrument's design with its goal.

31 The few exceptions that exist (Ashoff, 2005, McLean Hilker, 2004) use the term interaction without cross-referencing the interaction literature (Sorrell et al., 2003).

32 This is what Kern and Howlett (2009) refer to as congruence.

may slow down the envisaged transition of the energy system (ARD, 2013, WDR, 2013).

Consistency at these three levels may ultimately determine the effectiveness and efficiency of a policy mix. Yet, particularly due to the variety of often conflicting interests and the vertical and horizontal fragmentation of policy making, complete consistency of a given policy mix may be unlikely, if not impossible (Hoebink, 2004, McLean Hilker, 2004). This is particularly true when the boundaries of a policy mix study are broadly set.

4.2 Coherence of processes

To characterize policy processes we use the term *coherence*, thereby following studies that focus on the process dimension (Den Hertog and Stroß, 2011a, Jones, 2002, OECD, 2001, OECD, 2003a, OECD, 2003b). Given the ambiguity of the literature (see section 2.2), we suggest defining policy coherence as referring to the processes of policy making and implementation, ensuring that the elements of the policy mix are not in contradiction with one another or may even reinforce one another.

We highlight three key features of this coherence definition. First, it only addresses *policy processes*, thus explicitly excluding any characterization of the state of the policy mix. Second, the definition establishes a *positive link between coherence and consistency*, meaning that greater coherence is expected to be associated with greater consistency. However, coherence is not a sufficient condition or guarantee of consistency. Third, the definition is *comprehensive* as it encompasses all policy processes across different policy fields and governance levels (see section 3.3) and targets all elements of the policy mix. By including both policy strategy and interacting instruments we underline that none of the elements of the policy mix are seen as given.

Several studies discuss how to achieve coherence of policy processes (Ashoff, 2005, OECD, 1996, 2001). According to den Hertog et al. (2004), a number of structural and procedural mechanisms for strengthening coherence have been employed in OECD countries, such as strategic planning, coordinating structures and communication networks. Coherence enhancing measures also include leadership and commitment (OECD, 1996). For example, the Energiewende in Germany was declared as a top-level priority (‘Chefsache’) by chancellor Merkel, signaling leadership and commitment, although by itself this does not make up for inconsistencies in the policy mix (Die Welt, 2012). Two major tools for improving policy coherence are *policy integration* (OECD, 2003a, Underdal, 1980) and *coordination* (Bouckaert et al., 2010, OECD, 1996).[33] The former can improve policy coherence by enabling a more holistic thinking across different policy sectors, at the same time involving more holistic processes. In contrast, the latter can strengthen coherence by aligning the tasks and efforts of public sector organizations (Bouckaert et al., 2010), e.g. in enhancing information flows through formal mechanisms (OECD, 1996). For example, the establishment of an integrated energy and climate policy department, as accomplished in the UK and Denmark, seems to be a promising approach of structural coordination for overcoming the recurring conflict of jurisdictions between the German Federal Departments for the Environment (BMU) and Economics (BMWi) hampering the realization of the German Energiewende (Rave et al., 2013).

While both coherence and consistency are key characteristics of the policy mix, they should be seen as relative concepts, implying that it may well be impossible to actually achieve complete coherence and consistency (Carbone, 2008, McLean Hilker, 2004). This is because of the complexity of the systems, in which conflicting objectives between different policy fields or governance levels may be inevitable. Therefore, “the aim is to make progress towards maximum coherence within the limited resources available” (McLean Hilker, 2004), thereby striving to maximize policy mix consistency.

4.3 Other policy mix characteristics

In addition to consistency and coherence, other characteristics may also be relevant for describing the nature of a policy mix for environmental technological change, including credibility, stability and comprehensiveness (Foxon and Pearson, 2008, Majone, 1997, Matthes, 2010).

First, the *credibility* of a policy mix refers to the extent to which the policy mix is believable and reliable (Newell and Goldsmith, 2001)[34], both at an overall level

33 See definitions provided in footnotes 8 and 9. Also, while some studies view coherence as equivalent to integration and coordination (Duraiappah and Bhardwaj, 2007, Geerlings and Stead, 2003), we follow others in seeing them as distinct formalized tools for improving policy coherence (Carbone, 2008, Di Francesco, 2001, McLean Hilker, 2004, OECD, 2003a).

34 Policy credibility is rooted in macroeconomics and monetary policy, which examine the challenges that short time horizons (electoral cycles) pose for policy makers’ credibility (Kydland and Prescott, 1977).

and at the level of its elements or processes. Credibility may be influenced by a range of factors, such as the commitment from political leadership, the operationalization of targets by a consistent instrument mix and the delegation of competencies to independent agencies (see section 3.2.1). Ultimately, the perception of the credibility of the policy mix may play an important role in the achievement of policy objectives and thus in determining the effectiveness of the mix (Gilardi, 2002, Majone, 1997).

Second, *stability* characterizes the long-term certainty of the policy mix (del Río et al., 2010), which, however, does not mean that the mix cannot be adjusted to changing circumstances or new information. The stability of a policy mix may again be influenced by a range of determinants. One example regarding the policy strategy is the adherence to long-term targets, such as the EU's 20-20-20 targets, beyond electoral cycles. The stability of targets may be one factor influencing their credibility. Examples concerning policy processes and their impact on the stability of the policy mix include whether they are characterized by unscheduled ad-hoc changes or follow a well-known policy cycle, including advanced planning, prior announcements and stakeholder participation in light of envisaged changes to the policy mix. The degree of policy mix stability may impact the effectiveness and efficiency of the policy mix, for example through its effect on investor certainty.

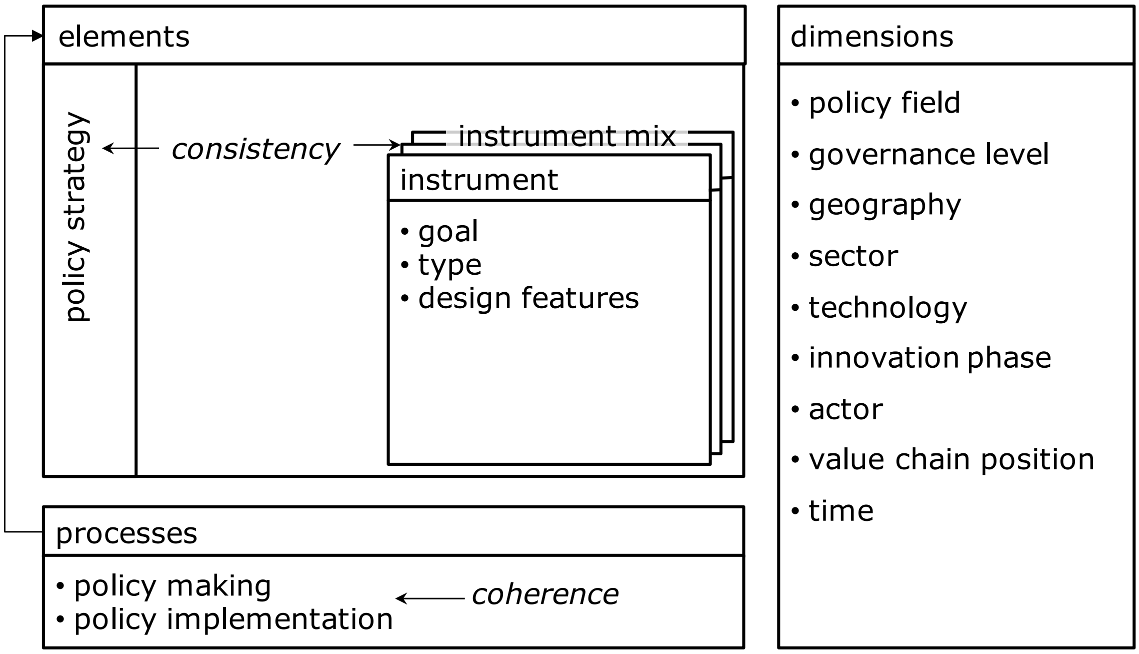
Third, *comprehensiveness* of the policy mix captures how extensive and exhaustive its elements are and the degree to which its processes are based on extensive decision-making (Atuahene-Gima and Murray, 2004, Miller, 2008) .That is, comprehensiveness of the elements of the policy mix can be determined by their scope. Examples include whether the policy mix is constituted both by a policy strategy and corresponding instruments, and the degree to which the instrument mix addresses all three instrument purposes of technology-push, demand-pull and systemic concerns. By contrast, the comprehensiveness of policy processes can be influenced by their structure, rigor and thoroughness (Atuahene-Gima and Murray, 2004). As with the other characteristics, the comprehensiveness of a policy mix may impact its performance according to various assessment criteria, such as its effectiveness and efficiency. Yet, as with all policy mix characteristics, there may be some tradeoffs. For example, greater comprehensiveness may make the mix more effective but less efficient.

5 Discussion

5.1 Synopsis

Having introduced the three building blocks and the policy mix characteristics, we now integrate them into a more comprehensive policy mix concept (see Figure 3) in which elements and processes constitute the core. The dimensions specify them and the characteristics describe the nature of the policy mix.

Figure 2: The policy mix concept



First, the *elements (E)* of the policy mix concept refer not only to the instrument mix – comprising interacting policy instruments characterized by their goals, type and design features – but also to the policy strategy, i.e. objectives including long-term targets and principal plans (section 3.1). The policy mix concept captures the state of affairs of these elements with the term 'consistency' for which three levels are distinguished (section 4.1): (1) consistency of the policy strategy; (2) consistency of the instrument mix, which is determined by the interaction of the instruments; and (3) consistency between policy strategy and instrument mix (as indicated by the double-sided arrow in Figure 3).

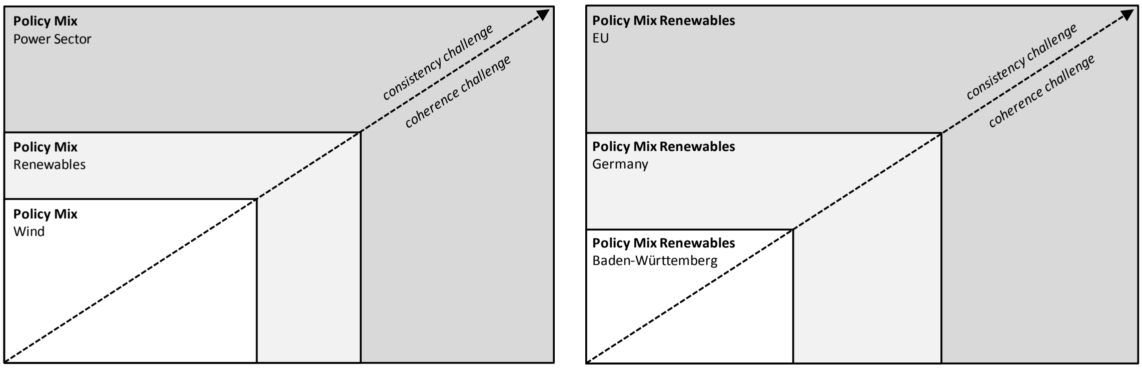
Second, in incorporating policy *processes (P)* the concept includes the procedures and institutional provisions of policy making and implementation (section 3.2). These processes determine the policy mix elements (as indicated by the left-sided arrow in Figure 3) and are characterized by the term 'coherence' (section 4.2). The concept assumes a positive link between coherence and consistency as the former may influence the state of the elements of the policy mix (see the left-sided arrow in Figure 3). Consistency, coherence and other characteristics of the policy mix are indicators of its nature and thus can feed into its evaluation using assessment criteria (see section 4).

Finally, the proposed policy mix concept reflects the complex and dynamic nature of policy mixes in its *dimensions (D)*. These can serve to specify elements and processes and their characteristics. For example, a study could analyze the temporal consistency of the policy mix *(D: time)*, its horizontal coherence *(D: governance level)*, the policy mix promoting a specific technology *(D: technology)*, or the most influential actors in the policy making process for a new policy instrument *(D: actor)*. As such, the dimensions can serve to set the boundaries of a policy mix.

Yet, the specification of the dimensions determines not only the scope of the policy mix but also the feasibility of achieving policy mix consistency and coherence. For example, a study of the policy mix regarding renewables could focus on one specific technology (e.g. wind), widen its scope to all renewable technologies or assume a holistic energy sector perspective, thereby covering all relevant niches as well as the sector regime, as illustrated in Figure 2 (a). In addition, taking the technological focus on all renewables as given, boundaries should also be determined concerning other key dimensions, e.g. regarding the vertical governance level, for which Figure 2 (b) provides some examples ranging from the state of Baden-Württemberg in Southern Germany to the EU. The wider the boundaries are set, the greater the scope of the policy mix and thus the greater the challenges for consistency and coherence, as indicated by the arrows in Figure 2 [35]

35 However, widening the system boundaries and thus the scope of the policy mix may actually allow for a more holistic perspective of the policy problem and lead to a better achievement of policy objectives.

Figure 3: Link between policy mix boundaries and consistency/coherence based on dimensions



(a) Dimensions technology & sector

(b) Dimensions technology & governance level

5.2 Illustration of the concept

In this section we illustrate the significance of the policy mix concept by discussing how its building blocks of elements *(E)*, processes *(P)* and dimensions *(D)* play out in real-world policy mixes. Taking the example of the German Energiewende we discuss some key policy mix challenges and relate these to the relevant policy mix terminology (indicated in italics). Currently, German policy makers and other stakeholders are preoccupied with reforming the EEG with its feed-in tariffs, the core instrument of the German policy mix for renewables *(E: instrument),* while neglecting other policy fields relevant for the Energiewende *(D: policy field)*. A key reason for these reform efforts lies in the effectiveness of the EEG in (over)achieving its goals for the diffusion of renewables in Germany *(E: instrument – goal)* (Ragwitz et al., 2012), and resulting high costs.[36] So far, this has been addressed by changing the EEG, e.g. adjusting goals upwards and tariffs downwards, and thus is an example of adaptive policy making *(E: instrument – goal, design features, P: policy making)*[37].

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36 The so-called 'EEG-Umlage' increased from initially 0.19 ct/kWh in 2000 to 3.59 ct/kWh in 2012, now representing a share of electricity costs of nearly 14 % for households (BMU, 2013b).

37 For the case of PV this policy process was described as compulsive policy making (Hoppmann et al., 2012).

Yet, due to the magnitude and sustained increase of the EEG costs, discussions are now underway about the (partial) substitution for the feed-in tariffs with other instruments *(E: instrument – type, instrument mix, P: policy making, D: time)* (Spiegel Online, 2013b). For example, future demand-pull instruments may include spatial specifications for priority areas for capacity additions that recognize the trade-off between physical potential, such as wind or sun, and the distance to demand centers and thus grid requirements *(E: instruments – type, design features, D: geography)*. That is, a future instrument mix *(E)* aiming at cost efficiency will not only have to consider EEG costs but also costs associated with building up additional grid infrastructure (Agora Energiewende, 2013).

Another example concerns the discussion of a retrospective adjustment of previously guaranteed feed-in tariffs received by plant operators, initiated by federal minister of the environment Peter Altmaier at the beginning of 2013 *(P: policy making, E: instruments – design features, D: actor)* (Spiegel Online, 2013a). His suggestion, which was later withdrawn *(D: time)*, shook the core beliefs of investors by questioning the so-called 'Bestandsschutz', or right of continuance, thus ultimately casting doubt on the predictability of the EEG as well as to some extent the credibility of the policy strategy *(E: instrument – design feature, policy strategy)*. While thus far the elements of the policy mix have remained unaffected, merely raising the question may have had a detrimental effect on investors and innovators (Spiegel Online, 2013c), illustrating the importance of including policy processes and their coherence within a comprehensive policy mix concept *(P: processes, coherence)*.

In this regard, the German government is pursuing several approaches to improve policy coherence *(P – processes, coherence)*. Renewables have been under the auspices of the German environmental department since October 2002[38], a structural change which may have improved policy coherence and eased the integrated consideration of demand-pull and technology-push and some of the systemic concerns of a transition to renewables *(P: policy making, coherence, E: instrument – type, instrument mix, D: policy field, time).*[39] More recently, the problematic developments regarding ever-increasing EEG costs and other concerns have been addressed by enhancing procedural coordination

38 See BMU (2013a) for an historical account of the development of the BMU and Rave et al. (2013) for an overview of all departments involved in different aspects of climate, energy and innovation policy.

39 This structural coordination may have contributed to the successful development of the German technological innovation systems for renewables (Walz and Ragwitz, 2011).

and thus policy coherence *(P: policy making, coherence, D: time)*, two examples being*:* First, a renewables platform was established on April 25, 2012 uniting federal and state-level policy makers from various departments *(D: governance level)* as well as non-governmental stakeholders *(D: actor, value chain, governance level)*[40] to jointly develop solutions to identified transition challenges (BMU, 2012). Second, a public debate about the EEG ("EEG-Dialog") was organized in a series of six meetings taking place from November 2012 to March 2013 to discuss problems, conflicts and alternative solutions regarding the reform of the EEG *(P: policy making, D: actor, technology, sector)*.[41]

Yet, considering the highly ambitious policy strategy associated with the Energiewende, these and other current political discussions and actions appear not systemic enough and instead to be too fragmented between climate, renewable and energy efficiency policy *(D: policy field)*. This is exemplified by the attention given to reforming the EEG *(E: instrument – design feature, type)*, while neglecting the reform of the EU ETS with its low carbon prices (FAZ, 2013, Germanwatch, 2013)[42], despite both instruments' interactions (del Río González, 2006) *(E: instrument mix, second level consistency)*. Also, while demand pull for renewables and systemic concerns regarding market design for the power sector are increasingly being discussed in an integrated manner, this seems to be neglected for technology push concerns *(P: policy making, E: instrument mix – type, D: sector, technology, time)*.[43] For example, none of the three working groups on the platform renewables prominently addresses the importance of combining demand pull with technology push instruments, de-

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40 For example, industry associations, grid companies, and environmental NGOs; see BMU (2012) for a complete list of participants.

41 The debate among different stakeholders was organized around different technologies (PV, biogas, wind, storage) as well as scenarios and costs *(D: technology)*.

42 EUA prices have dropped from ca. 22 € in the second half of 2008, to ca. 12 € in December 2010 and 6 € in December 2012 *(D: time)* and – with the failure to adopt "backloading" by the EU parliament on April 16, 2013 *(P: policy making)* – are now at a low of ca. 3-4 € / EUA (EEX, 2013).

43 One indicator of this neglect is the low value (4.8%) of the share of RES expenditures going to technology push instruments, with the rest associated with the demand pull costs of deployment instruments (Rave et al., 2013). Yet, the optimal balance between expenditures for demand-pull and technology push is an open question, whose answer may depend on several dimensions, e.g. which technology is being targeted and its innovation phase *(E: instrument mix – type, D: technology, innovation phase)*.

spite recommendations in this regard (Foray et al., 2012, Veugelers, 2012, Walz and Ragwitz, 2011).[44]

6 Conclusion

This paper contributes to the literature on environmental technological change in two major ways. First, it advocates a more *comprehensive concept* of the policy mix that takes into account the complexity and dynamics of real policy mixes and provides a uniform terminology applicable across academic disciplines. Specifically, the concept stresses that a policy mix goes beyond the combination of instruments – the instrument mix – but also includes a policy strategy and policy processes. In addition, the paper supports the precise use of key terms by providing uniform definitions, thereby enabling interdisciplinary research and enhancing the comparability of policy mix studies. A prime example in this regard is the suggested distinction between consistency (for elements) and coherence (for processes). Second, the paper provides an *interdisciplinary analytical framework* which may aid empirical research in at least two ways. On the one hand, the three building blocks of elements, processes and dimensions with their subcategories can help researchers set the boundaries of a policy mix study and thus concretize its scope and depth, bearing in mind the tradeoffs between the two. On the other hand, by explicitly differentiating between policy mix characteristics and assessment criteria, the paper points to the importance of studying the link between characteristics, such as coherence and consistency, and how these affect, for example, the effectiveness and (dynamic) efficiency of policy mixes. Ultimately, such a uniform terminology within a more comprehensive policy mix concept could pave the way for a fruitful exchange of currently still largely disconnected research efforts.

We derive three main policy implications. First, the paper underlines the importance of *thinking in terms of policy mixes* for environmental technological change, and it provides an analytical framework helpful in assuming such a

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44 The three working groups deal with deployment instruments (mainly EEG), coordination of deployment plans and impact for grids, and the interplay of renewable and fossil power generation technologies (BMU, 2012).

broader perspective.[45] More precisely, it highlights the need for policy makers to consider instrument mixes and instrument interactions along with the policy strategy with its long-term orientation as equally important elements of a policy mix. Second, since policy processes not only determine the elements of the policy mix but can also have a direct effect on the behavior of target actors, policy makers need to work on improving both the consistency of the elements of the policy mix and the *coherence of policy processes*. However, coherence and consistency are not ends in themselves but are mainly relevant through their effects on the effectiveness and efficiency of a policy mix. Third, the paper underlines the necessity to assume a *system perspective in policy making.* For example, an instrument mix should not only address demand pull or technology push but cover all concerns, including systemic ones. In addition, even when reforming a single instrument, policy makers aiming at promoting environmental technological change or working on the objective 'Energiewende' need to keep in mind how the proposed changes affect the consistency of the overarching policy mix. This requires systemic capabilities, e.g. in terms of assessing the needed changes to an existing policy mix to promote the functioning of the relevant innovation system. Such capabilities could be supported through coherent policy processes and further developed through policy learning.

The policy mix concept proposed in this paper is not without its limitations. First, since it has been developed for environmental technological change, it may not be directly applicable to sustainability transitions or generalizable to other societal challenges. Still, the concept may serve as a useful starting point. Second, the comprehensiveness of the policy mix concept proposed here comes at the cost of providing only a rather aggregated overview of the three building blocks, their characteristics and their interplay.

Thus, we envisage three areas for future research. First, the policy mix concept proposed here should be further developed by a more detailed examination of each of the three building blocks. In this regard, it may be especially promising to explore in more depth the nature of policy processes and their coherence, and their influence on the elements of a policy mix and their consistency. A se-

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45 This could be further promoted by adapting existing policy databases and their search categories, such as IEA's policies and measures (http://www.iea.org/policiesandmeasures/), the EU's MURE database (www.muredatabase.org) and the website on regulations on renewable energy generation (www.res-legal.eu) to better reflect the different elements (and processes) of the policy mix and their dimensions and thus facilitate greater access of information about policy mixes.

cond promising field of future work represents the integration of the policy mix concept with other research approaches, such as studying the co-evolution of policy mixes and innovation systems, or applying the policy mix concept within the multi-level perspective for studying socio-technical transitions. Finally, empirical studies would benefit from applying the analytical framework proposed here to better understand the role of the policy mix for environmental technological change, as evaluated by key assessment criteria, such as its effectiveness or dynamic efficiency, e.g. through case studies, company surveys, patent analyses or modeling. Within this research, a key methodological challenge will be operationalizing policy mix elements, processes and their characteristics, and disentangling their effects, such as for the illustrated case of the policy mix for renewables. Ultimately, by increasing our understanding of the role of the policy mix for environmental technological change such empirical studies may constitute one major foundation for addressing the challenge of how to design and implement policy mixes for sustainability transitions.

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Annex

Table 6: Definitions of strategy

Source	**Definition**
Drucker (1973) (p.120)	“the continuous process of making present entrepreneurial (risk-taking) decisions systematically and with the greatest knowledge of their futurity; organizing systematically the efforts needed to carry out these decisions; and measuring the results of these decisions against the expectations through organized, systematic feedback.“
Porter (1980) (p. XXIVf.)	“[…] competitive strategy is a combination of the ends (goals) for which the firm is striving and the means (policies) by which it is seeking to get there.”
Andrews (1987) (p. 13)	„Corporate strategy is the pattern of decisions in a company that determines and reveals its objectives, purposes, or goals, produces the principal policies and plans for achieving those goals, and defines the range of business the company is to pursue”
Elmore (1987) (p.181)	“[…] corporate strategy is typically used to characterize ‘the pattern of purposes and policies defining the company and its business,’ or the ‘choice of purposes [and] the essential policy-level means for achieving it.’” “choice of purposes and essential policy-level means for achieving it”
Grant (2005) (p.18)	“At its most general level, strategy is concerned with planning how an organization or an individual will achieve its goals.”

Table 7: Definitions of "policy instrument"

Source	Definition
Salamon 2002, p.19	"A tool, or instrument, of public action is an identifiable method through which collective action is structured to address a public problem."
Sorrell et al. 2003, p.15	"This is the legislation, law, regulation, initiative etc. which has been introduced by a governing body to address a particular problem and achieve one or more specified objectives. Objectives are desired policy outcomes."
Howlett, Rayner 2007, p.2	"Policy instruments are techniques of governance which, one way or another, involve the utilization of state resources, or their conscious limitation, in order to achieve policy goals."
Nauwelaers et al. 2009, p.4	"All programmes, organizations, rules and regulations with an active involvement of the public sector, which intentionally or unintentionally affect R&D investments."
de Heide 2011, p.3	"A policy instrument (also called measure or tool) translates the plan of action and its accompanying objectives and goals as defined by a public policy into concrete interventions."

Table 8: Selected instrument types in interdisciplinary studies in the environmental domain

Source	Instrument types
UNFCCC (2000)	• Economic, fiscal, voluntary/ negotiated agreements, regulatory, information, education, research, other
Rennings et al. (2008)	• Innovation policy: project support, fostering of networks & technology transfer • Environmental policies for eco-innovation: market-based instruments to foster environmental technical progress, instruments to foster specific eco-innovation, supply- and demand-side measures to foster diffusion of environmental technologies
Taylor (2008)	• Upstream investment, market creation, interface improvement
del Río (2009b)[46]	• Environmental policy instruments: CAC, market-based, environmental management systems, voluntary agreements, information disclosure programs • Technology policy instruments: government funding of RD&D, training on new technologies, technological assistance, creation of protected niches for emerging cleaner technologies (Strategic Niche Management), public procurement, technological foresight studies, environmental technology awards and creation of a network of actors involved in environmental technological change, subsidies for adoption of cleaner technologies, information provision to firms
IEA (2011)	• Price-based, command and control regulations, technology support policies, information and voluntary approaches
IEA (2012)	• Economic instruments: direct investment, fiscal/ financial incentives, market-based instruments • Information & education: advice/ aid in implementation, information provision, performance label, professional training and qualification • Policy support: institutional creation, strategic planning • Regulatory instruments: auditing, codes and standards, monitoring, obligation schemes, other mandatory requirements • RDD: demonstration project, research program • Voluntary approaches: negotiated agreements, public voluntary schemes, unilateral commitments

46 Del Rio et al. (2010) also highlight the usefulness of long-term visions for integrating environment and technology policies.

Table 9: Types of interaction according to Sorrell et al. (2003)

Type of interaction	Meaning
Direct	Two policy instruments impact upon a target group at the same time
Indirect	One or both policy instruments impact upon a target group indirectly
Operational	Joint operation of policy instruments so that either a certain target group moves from one policy to the other or that the contents of one policy are deliberately modified by the coexistence of the other
Sequencing	Changes in policies over time in that one policy with effects on certain actors is superseded by another policy affecting the same actors

Table 10: Categories of interaction outcomes

Source	Outcomes of interaction
Gunningham, Grabosky 1998 [also applied in Sorrell et al. (2003)]	Complementary
	Incompatible
	Complementary if sequenced
	Context specific
del Río 2009, 2010; IEA 2011	Positive
	Negative
	Neutral/ no interaction

Table 11: Selected list of policy instrument design features in the literature

Source	Design features
Kemp and Pontoglio (2011), p.34	• Stringency • Predictability • Differentiation with regard to industrial sector or the size of the plant • Timing: the moment at which they become effective, the use of phase-in periods • The credibility of policy commitments to future standards • Possibilities for monitoring compliance and discovering non-compliance • Enforcement (inspection and penalties for non-compliance) • Combination with other instruments of policy
Haščic et al. (2009)	• Stringency, i.e. how ambitious is the environmental policy target, relative to the baseline trajectory? • Certainty, i.e. what effect does the policy measure have on investor uncertainty? • Incidence, i.e. does the policy target directly the externality, or is the point of incidence a proxy for the pollutant? • Depth, i.e. are there incentives to innovate throughout the range of potential objectives? • Flexibility, i.e. does it let the innovator identify the optimal way to meet the objective?
Kivimaa (2007), p. 102	• Foreseeability of policies: sufficient response times in policy planning, consistency of different policies • Continuous improvement: progressively more demanding policies • Flexibility of policies: instruments that allow multiple solutions and responses, exceptions for testing innovation
Norberg-Bohm (1999), p. 16	• Stimulation of industry-generated information • Providing economic or political incentives • Reducing long-term uncertainties • Providing flexibility

Figure 4: Explanation of the elements of the policy mix for renewables in Germany (policy strategy and instrument mix) listed in Figure 1

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

Table 12: Selected definitions of the term consistency

Source	Definition of CONSISTENCY
den Hertog, Stroß (2011) (p.4)	"the absence of contradictions within and between individual policies."
EU Parliament (2010) (Article A)	"Avoiding contradictions among different (…) policy areas"
Kern, Howlett (2009) (p.395)	"policy tools are consistent when they work together to support a policy goal. They are inconsistent when they against each other and are counterproductive, for example, providing simultaneous incentives and disincentives toward the attainment of stated policy goals."
Pal (2006) (p.11)	"internal consistency among the three elements of problem definition, goals, and instruments."
OECD (2003b) (p.2)	"the process ensuring that policy objectives are delivered and that they are not contradictory"
Tietje (1997) (p.212)	"Consistency in law is the absence of contradictions; coherence on the other hand refers to positive connections. Moreover, coherence in law is a matter of degree, whereas consistency is a static concept"

Table 12: Selected definitions of the term coherence

Source	Definition of COHERENCE
Nilsson et al. (2012) (p.2)	"We define policy coherence as an attribute of policy that systematically reduces conflicts and promotes synergies between and within different policy areas to achieve the outcomes associated with jointly agreed policy objectives."
den Hertog, Stroß (2011) (p.4, 8)	"Policy coherence refers to the synergic and systematic support towards the achievement of common objectives within and across individual policies."
Kern, Howlett (2009) (p.395)	"policy goals are typically considered as coherent if they are logically related to the same overall policy aims and objectives and can be achieved simultaneously without any significant trade-offs. They are incoherent if they contain major contradictions, i.e. goals that cannot be achieved simultaneously and lead to the attainment of only some or none of the original objectives"
Mickwitz et al. (2009) (p.24)	"Policy coherence is used to imply that the incentives and signals of different policies – climate and others – provide target groups with non-conflicting signals. "
May et al. (2006) (p.382)	"In common parlance, coherence implies that various policies go together because they share a set of ideas or objectives."
Whinship (2006) (p.113)	"Achievement of a situation in which multiple and potentially conflicting ends are in fact compatible ."
Ashoff (2005) (p.112)	"The absence of incoherencies, which occur when other policies deliberately or accidentally impair the effects of development policy or run counter to its intentions, i.e. of inconsistencies between and the mutual impairment of different policies" [negative] "Support for development policy from other policies or […] the interaction of all policies that are relevant in the given context with a view to achieving overriding development objectives" [positive]
Geerling, Stead (2004) (p.188)	"policy co-ordination, policy coherence and policy consistency—all quite similar, which imply co-operation plus transparency and some attempt to avoid policy conflicts (but do not necessarily imply the use of similar goals)."
McLean, Hilker (2004) (p.5)	"Means working to ensure that the objectives and results of a government's (or institution's) development policies are not undermined by other policies of that government (or institution), which impact on developing countries, and that these other policies support development objectives where feasible." [also used without referring to "institution" by EU Parliament 2010]

Source	Definition of COHERENCE
OECD (2001) (p.104)	"Involves the systematic promotion of mutually reinforcing policy actions across government departments and agencies creating synergies towards achieving the defined objective" [also used by Jones 2002]
Smith (2001) (p.2)	"Positive connections"
Forster, Stokke (1999) (p.23)	"Coherence may, accordingly, be defined as a policy whose objectives, within a given policy framework, are internally consistent and attuned to objectives pursued within other policy frameworks of the system — as a minimum, these objectives should not be conflicting; where strategies and mechanisms are attuned to the objectives, they should, as a minimum, not conflict with the objectives or with the intentions and motives on which these are based; and where the outcome is corresponding to the intentions and objectives, it should, as a minimum, not conflict with these." [state of affairs definition]
OECD (1997) (p.8)	"In its broadest sense, coherence implies an overall state of mutual consistency among different policies." [cited by Di Francesco 2001]
Mc Farlane D. R. (1989) (p.395)	"The statutory coherence hypothesis states that effective implementation is a function of the extent to which a statute coherently structures the implementation process."

Table 13: Selection of instrument types in the literature of different scientific fields

	Source	Instrument types
Policy analysis	Lowi (1972)	• Distributive, regulative, constituent, redistributive
	Hood (1983)	• Role of government: detecting, effecting • Governmental resource: nodality, treasure, authority, organization
	Görlitz, Burth (1998)	• Regulating, structuring, financing, informing
	Gunningham, Grabosky (1998)	• Command and control regulation, economic instruments, self-regulation, voluntarism, information strategies
	Braun, Girod (2003)	• Ensuring public goods and resources: state sovereign rights, state as supplier of goods and services, • Influencing of societal action: direct taxes (regulative policy), indirect taxes (financing, structuring, convincing)
	Vedung (2007)	• Regulation (sticks), economic means (carrots), information (sermons)
Environmental economics	Kemp (1997a)	• Environmental standards, economic incentives, R&D subsidies, covenants, communication
	Hemmelskamp (1999a)	• Regulatory: emission constraint, application constraint • Economic: environmental levies, certificates, subsidies; privatization models, environmental liability law • Informational: environmental management and audit, environmental controlling, ecologic marketing, cooperation solutions, environment signs
	Sterner (Sterner, 2000)	• Using markets: subsidy reduction, environmental taxes, user charges, deposit-refund systems, targeted subsidies • Creating markets: property rights, tradable permits & rights, international offset systems • Environmental regulations: standards, bans, permits and quotas, zoning, liability • Engaging the public: public participation, information disclosure
Innovation studies	Dasgupta (1988)	• Subsidies to foster innovation, institutions to create and enforce property rights, government expenditure/ procurement
	Mowery (1995)	• Supply policies: basic RDD, exploiting research infrastructure • Adoption policies: e.g. subsidies for technology adoption, information provision programs, government procurement • Competition policy
	Edler, Georghiou (2007)	• Supply-side measures: finance (e.g. fiscal measures, equity support), services (e.g. information) • Demand-side measures: systemic policies, regulation, public procurement, support of private demand

Source	Instrument types
Nauwelaers et al. (2009)	• R&D domain: R&D policies (generic, sectoral), R&D/ innovation policies (linkage policies, IPR policies), R&D specific finance policies, R&D specific human capital policies (R&D specific education and employment policies) • Finance domain: financial and fiscal policies (non-R&D specific), macroeconomic policies • Human capital domain: education policies (non-R&D specific), employment policies (non-R&D specific) • Innovation domain: innovation policies (generic, sectoral), other policies (e.g. industry, trade, defense policies)
Rammer (2009)	• Provision of public goods, financial subsidies, state loans, state equity assistance, tax concessions, programs for information/ consultancy/ training, provision of technological infrastructure, regulations
Hufnagl (2010)	• Distribution: direct provision of resources, indirect provision of resources • Regulation: systemic management, law-creating measures • Information: conveyance of information, policy expertise, discursive instruments

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