Energy Research & Social Science xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Conceptual and empirical advances in analysing policy mixes for energy transitions

Karoline S. Rogge[a,b,*], Florian Kern[a], Michael Howlett[c,d]

[a] SPRU-Science Policy Research Unit, University of Sussex, UK
[b] Fraunhofer Institute Systems and Innovation Research ISI, Karlsruhe, Germany
[c] Department of Political Science, Simon Fraser University, Canada
[d] Lee Kuan Yew School of Public Policy, National University of Singapore, Singapore

ARTICLE INFO

Keywords:
Policy mix
Energy transitions
Policy processes
Policy strategy
Consistency
Coherence

ABSTRACT

Energy transitions face multiple barriers, lock-in, path dependencies and resistance to change which require strategic policy efforts to be overcome. In this regard, it has been increasingly recognised that a multiplicity of instruments – or instrument mixes – are needed to foster low-carbon transitions. In addition, over the past few years a broader conceptualization of policy mixes for sustainability transitions has emerged which we adopt in this special issue. Such a broader perspective not only examines the interaction of instruments, but also captures corresponding policy strategies with their long-term targets and pays greater attention to the associated policy processes. It also encompasses the analysis of overarching policy mix characteristics such as consistency, coherence or credibility, as well as policy design considerations. Furthermore, it embraces the analysis of actors and institutions involved in developing and implementing such policy mixes. To explicitly consider these further aspects of policy mixes, this special issue includes fifteen papers with different analytical perspectives drawing on a range of social science disciplines, such as environmental economics, innovation studies and policy sciences. It is our hope that the conceptual and empirical advances presented here will stimulate diverse future research and inform policy advice on policy mixes for energy transitions.

1. The importance of policy mixes for energy transitions

The Paris Agreement calls for the rapid decarbonisation of the global energy system to limit temperature increases to well below 2 °C. Since fossil fuel use in the energy sector is one of the main contributors to global carbon emissions, achieving this goal requires a global transition away from carbon-intensive energy systems towards low carbon configurations. Such transitions can be understood as dynamic processes of structural change in the way energy is produced and used, and have historically taken place over long-time horizons [1–3].

Over the last 15 years a burgeoning, interdisciplinary literature has developed on how such transitions occur [4,2,5–10]. The sustainability transitions literature conceptualises transitions as co-evolutionary processes that involve technological innovations and their use in societal applications. As such, transitions are multi-actor processes, involving a large variety of social groups. They are characterized by radical shifts from one socio-technical configuration to another; and are often long-term processes taking several decades ([3,91]).

This is because transitions face multiple barriers, including lock-in into high carbon, fossil fuel based technological trajectories, path dependencies and resistance to change from incumbent industries benefitting from the current socio-technical configurations. For example Unruh [11] has powerfully argued how industrial economies have been locked into fossil fuels based energy systems through a process of technological and institutional co-evolution which is driven by path dependent increasing returns to scale. One form of path dependency is cognitive lock in as firms normally continue innovating along established paths ('normal' problem solving) rather than trying something radically new (technologies or business models). This process has been described as technological trajectories [12] which are hard to shift. Also Walker [13] has shown that organisational commitments and vested interests in the continuation of systems, even when economically obsolete, can create inertia, causing inferior technologies and technology paths to survive. These obstacles mean that low carbon transitions require strategic policy efforts to be overcome [14,15]. Without such policies, these problems enforce the stability of existing unsustainable, high carbon energy systems and prevent transitions from occurring [11,5].

Public policy is hence key to promoting energy transitions in terms of both their speed and direction [5,16,7,17]. While much of the early

* Corresponding author at: SPRU - Science Policy Research Unit, University of Sussex, BN1 9SL Brighton Falmer, UK.
E-mail address: k.rogge@sussex.ac.uk (K.S. Rogge).

http://dx.doi.org/10.1016/j.erss.2017.09.025
Received 9 September 2017; Received in revised form 19 September 2017; Accepted 21 September 2017

literature on addressing climate change focused on discussions about specific instruments suitable for internalising negative externalities arising from greenhouse gas emissions (tax versus trading) [18,19], it has been increasingly recognised that a multiplicity of instruments is needed to foster successful transitions [20–22].

This shift away from striving for one instrument as the silver bullet to a recognition that well designed combinations of instruments are needed for fostering transitions may still be contested by some. Yet, even economists increasingly acknowledge that tackling climate change may require not only carbon pricing but also complementary instruments [23]. Empirically, even in jurisdiction where an emission trading system (ETS) as one way of pricing carbon has been introduced (such as in the EU), alongside this policy instrument a wide range of other instruments exist, thereby addressing several market and system failures. For example, the progress of the German electricity transition towards renewable energies, arguably largely hinged upon a policy design which combined feed-in tariffs and priority access to the grid, as well as specific long-term expansion targets, under the umbrella of one law, the EEG, thereby complementing the EU ETS [24–26]. This example also illustrates that other policy mix considerations played a key role, as well, such as the simultaneous existence of the nuclear phase out, the promotion of research and development, or the credibility, consistency and coherence of the overarching policy mix [27,24,28]. That is, while some instruments may be considered as core, such as feed-in tariffs for the promotion of renewable energies or carbon pricing for reducing greenhouse gas emissions, what matters for achieving the objectives associated with ambitious low-carbon energy transitions is not only their design but how well they are embedded in a policy mix [29].

Furthermore, any attempt to govern energy transitions does not start on a bare slate but is always embedded in pre-existing policy contexts with legacies of instruments from earlier policy eras still in place [30]. It is this complicated, messy reality which influences policy outcomes rather than economic textbook considerations around ‘first best’ policy options and ‘optimal’ policy design. The policy mix literature is an attempt to make sense of this empirical complexity while simultaneously acknowledging a diverse set of policy rationales calling for policy mixes rather than single policy instruments. It is therefore increasingly important to explicitly study policy mixes, how they can be designed and how they can be implemented in order to promote deliberate sustainability transitions [31,29].

Various definitions for such policy mixes exist (see Table 1), with the most basic ones focusing simply on a number of multiple policy instruments and how they are combined in instrument mixes [32,20,23]. Correspondingly, much of the research on policy mixes for important sustainability areas such as energy transitions has so far mainly focused on the analysis of interactions of policy instruments designed to affect the operation of energy systems [35–38]. However, broader understandings of policy mixes pay greater attention to other aspects of such mixes as well, especially those related to policy processes and how they affect the characteristics of policy mixes, including such issues as policy integration and coordination across multiple sectors and levels of government ([39,29,40,92]).

However, given its novelty, empirical applications and analyses applying such extended policy mix conceptions have so far been limited [28,41,42]. It is therefore the aim of this special issue to collect emerging conceptual and empirical advances adopting such a broader conceptualization of policy mixes in order to study and assess the means and mechanisms for energy transitions. The special issues thus includes papers examining not only interacting instruments, but also corresponding policy strategies and their long-term targets, policy processes as well as overarching policy mix characteristics such as consistency, coherence or credibility and policy design considerations. In addition, the special issue engages with the analysis of the actors and institutions involved in developing and implementing such mixes in the energy case. Consequently, the analytical perspectives in this special issue draw on a range of social science disciplines, such as environmental economics, innovation studies and policy sciences to explicitly consider further aspects of such policy mixes. These different perspectives on policy mixes will be briefly introduced in the next section.

2. Disciplinary perspectives on policy mixes

The emerging literature on policy mixes for sustainability transitions builds on three key disciplinary foundations: environmental economics, innovation studies, and policy sciences. Unfortunately, these three fields have so far developed largely independently of each other, with little attempts of cross-fertilization. As a consequence, each has developed its own understanding of what constitutes a policy mix and how key terms should be defined, thereby rendering interdisciplinary dialogue difficult (see Table 1 and Fig. 1).

Table 1
Three main fields addressing policy mixes with exemplary definitions.

Field	Examples of policy mix definitions
Environmental economics	• Instrument mixes are defined as a situation in which “several – instead of one – policy instruments are used to address a particular environmental problem”. ([32], p. 186) • “The need for a policy mix has been recognised by many governments, but experience to date has been that the interactions among multiple policies are often not well understood nor well coordinated, which can lead to policy redundancy or policies undermining one another, reducing the effectiveness and efficiency of the overall package.” ([20], p. 60) • “Polluting sources may be affected directly or indirectly by several policies addressing the same pollution problem. This is referred to as a policy mix [..].” ([23], p. 1)
Policy sciences	• Limitations in environmental policy “can only be overcome by invoking a broader vision of regulation and by the pursuit of broader policy mixes, utilizing combinations of instruments and actors, and taking advantage of various synergies and complementarities between them." ([33], p. 5) • “Policy mixes are complex arrangements of multiple goals and means which, in many cases, have developed incrementally over many years.” ([30], p. 395)
Innovation studies	• “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.” ([34], p. 3) • “[..] policy mixes favourable to sustainability transitions need to involve both policies aiming for the ‘creation’ of new and for ‘destroying’ (or withdrawing support for) the old.” ([31], p. 206) • “[..] we define the policy mix as a combination of the three building blocks elements, processes and characteristics, which can be specified using different dimensions. Elements comprise the (i) policy strategy with its objectives and principal plans for achieving them and (ii) the instrument mix with its interacting policy instruments. The content of these elements is an outcome of policy processes. Both elements and processes can be described by their characteristics, including the consistency of elements, the coherence of processes, as well as the credibility and comprehensiveness of a policy mix. Finally, the policy mix can be delineated by several dimensions, including policy field, governance level, geography and time.” ([29], p. 1622f.)

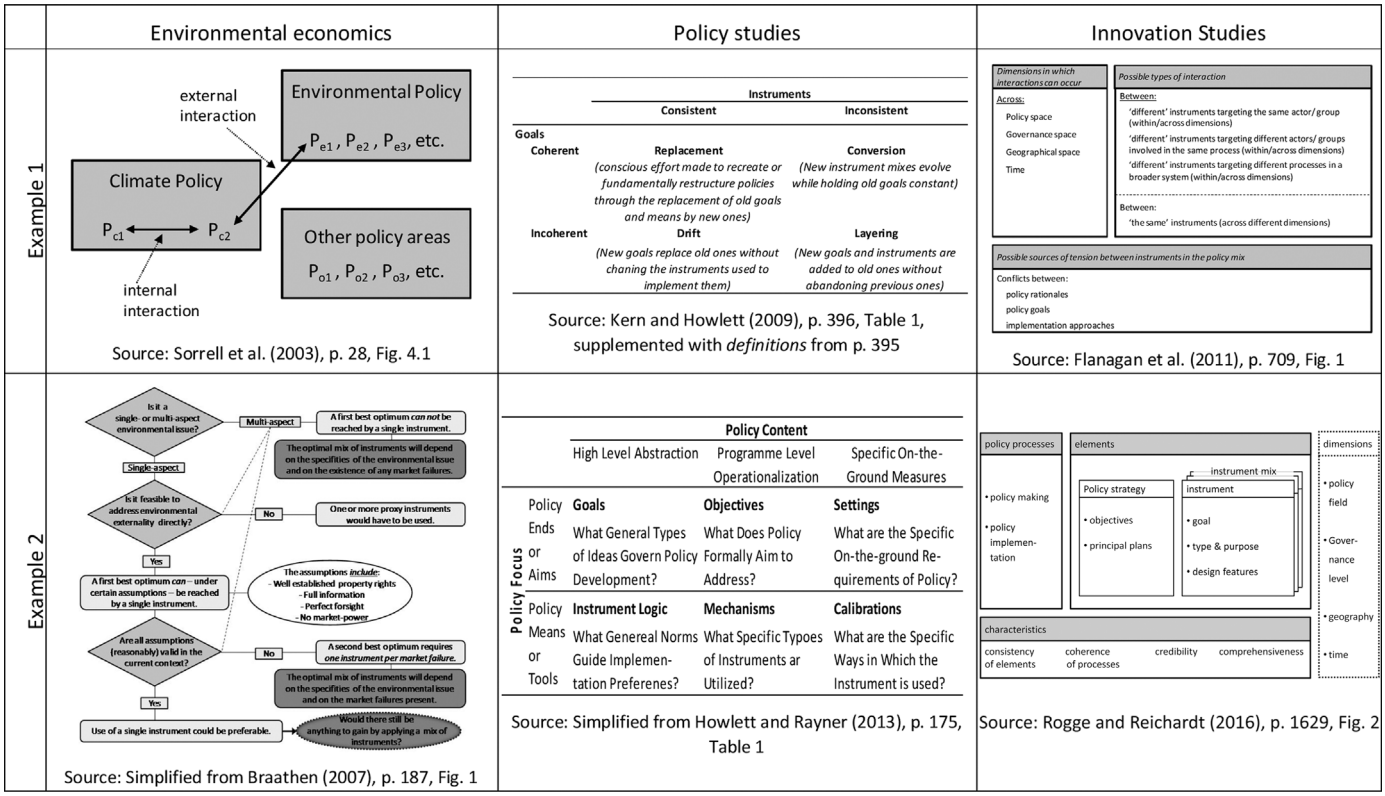

Fig. 1. Exemplary visualizations of a range of policy mix conceptualizations from the three fields.
Source: Own compilation of [29,30,32,37,47,89].

Much research focusing on the advantages and disadvantages, or strengths and weaknesses of different combinations of instruments and their interactions draws on *environmental economics*. Here, the rationale for using multiple policy instruments is said to rest on the existence of multiple market failures, each of which can be addressed by a different tool [43,32,23]. Therefore, the corresponding analyses of policy instrument mixes found in this field is often concerned with designing an optimal combination of policy instruments put in place to address specific failures with the idea that (a) some failures can be addressed by many different tools and (b) some combinations of tools are more 'complementary' than others in that some tools can supplement or reinforce market corrections [44,45]. The idea that some mixes can be sub-optimal poses a range of questions about how such instruments interact with each other and with over-riding market and government failures, and how this impacts the effectiveness and efficiency of policy interventions singly and as a whole. Much of this work has focused on interactions between the EU emissions trading system (EU ETS) and other climate and energy policy instruments ranging from producer regulations to individual household consumption incentives and disincentives [35,36].

In contrast, the thinking about policy mixes from the field of *policy sciences* includes the analysis of both instruments and the goals they are expected to achieve, of which correcting market failures is seen at best as only one among many [46,40]. That is, the assessment of policy mixes is based on overall policy mix characteristics such as not just the consistency of multiple instruments, but also the coherence of multiple goals, and the congruence between instruments and goals, often in the context of multiple governments and governmental actions over time [30,42]. The potential 'fit' of proposed new policy programmes or instruments with their governance context is also considered important [47] and an important issue of interest is "how specific types of policy tools or instruments are bundled or combined in a principled manner into policy 'portfolios' or 'mixes' in an effort to attain policy goals" (). Importantly, one of the main starting points of this literature is that new policy developments are almost always constrained by previous policy choices, whereas situations where completely new policy mixes are developed are considered to be quite rare. Thus, an important question in this field is the evolution of policy mixes and the processes through which such change happens. Drawing on institutional theory, Howlett and Rayner [47] for example have suggested that policy mixes typically evolve through four processes: layering, drift, conversion and replacement ([90]).

Finally, the interdisciplinary field of *innovation studies* has also relatively recently taken a specific interest in questions around the role of policy mixes in promoting technological and other kinds of innovations, with several contributions published over the last decade in *Research Policy* [39,48–51,31,29] and other innovation studies journals [52,53,28,54] on these subjects. Some of these contributions mirror the interest of environmental economists in instrument interactions around market and government failures seen as barriers to innovation [49,51]. However most of this work adopts a broader perspective on mixes in which, as with the policy sciences view, the dynamic nature of policy mixes, the importance of policy processes, the relevance of long-term targets and the challenges for policy coordination are all stressed [39,55,56]. Such a broader perspective on policy mixes is argued to be particularly relevant for innovations required for sustainability transitions [29], and includes, among others, the explicit consideration of policies promoting creative destruction [31] and of policy mix characteristics, such as the consistency of policy mix elements and the coherence of policy processes which can allow such policies to develop and be implemented successfully [28,41].

Given the terminological variety and sometimes conflicting definitions of some core concepts used within the policy mix literature, and to facilitate constructive dialogue across different fields, in Table 2 we provide an overview of selected policy mix components and some of their key definitions, as applied in the contributions of this special issue.[1]

[1] Listing all definitions used within the policy mix literature would be beyond the scope of this SI introduction.

Table 2
An overview of key definitions of policy mix components utilized in this special issue.

Term	Key definition(s) of policy mix components found in this special issue (and source)
Policy instruments	• "[..] are techniques of governance that, one way or another, involve the utilization of state authority or its conscious limitation." ([57], p. 31) • "[..] constitute the concrete tools to achieve overarching objectives. [..] A number of alternative terms are used, such as implementing measures [.], programs [.], policies [.], or policies and measures [.]." ([29], p. 1623)
Design features of policy instruments	• "Design features can be differentiated by abstract and descriptive features. Descriptive design features, such as an instrument's legal form, its target actors, and its duration, summarize the content of a policy instrument [.]. A number of abstract design features [.] may be important to consider: stringency, level of support, predictability, flexibility, differentiation and depth." ([29], p. 1624)
Instrument interactions	• "[..] interactions between instruments might be positive, when the performance of one or both examined instruments against a criterion increases because of their coexistence, or negative when the combined policies lead to negative impacts that would not have occurred by either alone." ([35], p. 421) • "[..] interactions between instruments targeting the same actor or group of actors, interactions between instruments targeting different actors/groups involved in the same process, and interactions between instruments targeting points of action which may otherwise seem to be far removed but which interact because the processes or actors targeted prove ultimately to be linked by other processes in a broader 'system'. To these we would add [.] the possibility that 'the same' instruments will interact with each other across one or more often possible dimensions (for instance, between different levels of governance or over time)." ([39], p. 710)
Policy strategy	• "[..] composed of the following three building blocks [..]: Strategy content, composed of policy objectives and the measures designed to achieve them; Strategy process, encompassing the process of policy development, implementation and adaptation; Strategic capacity, including capacities needed for policy development, implementation and learning as well as the engagement of stakeholders." ([50], p. 235) • "[..] a combination of policy objectives and the principal plans for achieving them. That is, the definition puts an emphasis on the output – the ends and means – of the strategy process, while the adaptive process of formulating, implementing and revising objectives and plans is captured by the processes building block [.]." ([29], p. 1623)
Policy process	• "Policy process research can be defined as the study of the interactions over time between public policy and its surrounding actors, events, and contexts, as well as the policy or policies' outcomes." ([58], p. 5) • "[..] political problem-solving process among constrained social actors in the search for solutions to societal problems – with the government as primary agent taking conscious, deliberate, authoritative and often interrelated decisions. As such, these interactive and continuous reconciliation processes with various feedback loops involve power, agency and politics." ([29], p. 1625)
Consistency/coherence/congruence	• "[.] 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 [.] Policy tools are *consistent* when they work together to support a policy goal. They are *inconsistent* when they work against each other and are counterproductive, for example, providing simultaneous incentives and disincentives toward the attainment of stated policy goals [.]." ([30], p. 395) "[.] they also suggest the importance of the third element of a policy mix, namely the *congruence* of goals and means in any policy mix." ([30], p. 401) • "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 and Stroß [59] found a lack of delineation between the terms coherence and consistency. Similarly, a potential source of confusion is arguably the lack of delineation between policy integration and policy coherence. As seen above, many coherence studies have tended to focus on procedural aspects [.]. The approach taken in this study to delineate policy coherence analysis is to focus on policy outputs (including objectives and associated implementation arrangements), whereas policy integration analysis is primarily concerned with upstream policy making processes and the associated institutional arrangements." ([60], p. 396) • "We suggest that *consistency* captures how well the elements of the policy mix are aligned with each other, thereby contributing to the achievement of policy objectives. It may range from the absence of contradictions [weak consistency] to the existence of synergies [strong consistency] within and between the elements [policy strategy and instrument mix] of the policy mix. [.] We distinguish between consistency of the policy strategy [first level consistency], consistency of the instrument mix [second level consistency], and consistency of the instrument mix with the policy strategy [third level consistency. [.] To characterize policy processes we use the term *coherence*, [.] defining policy coherence as referring to synergistic and systematic policy making and implementation processes contributing – either directly or indirectly – towards the achievement of policy objective. [.] may be achieved through a number of structural and procedural mechanisms, such as strategic planning, coordinating structures and communication networks [.]. Two major tools for improving policy coherence are policy *integration* [.] and *coordination* [.]." ([29], p. 1626f.)

3. Aims of the special issue

The papers in this special issue generally adopt a broad perspective on policy mixes governing energy transitions combining the disciplinary perspectives described above. In so doing the authors pursue the aims of the special issue, which include:

1. To increase the visibility of the topic of policy mixes for energy transition studies within the field of energy research by showcasing novel conceptual and empirical approaches to the subject;
2. To promote conceptual innovations in the way energy transition scholars understand and study policy mixes by bringing together a multi-disciplinary collection of authors who draw on different disciplinary evidence, cases and approaches to the subject; and
3. To provide reflections on the state of the emerging literature on policy mixes for future research and practice related to energy transitions.

The contributions to this special issue were selected through a competitive process. The guest editors published an open call for contributions in July 2016 through relevant mailing lists (e.g. Energy-l, Climate-l, STRN) and other means to identify potential contributions. In response to our call we received 65 extended abstracts (1500 words).[2]

[2] Because of the large number of high quality abstracts received in response to our CfP we are also acting as guest-editors for a second special issue which focuses more broadly on policy mixes for sustainability transitions and is intended to be published in the journal

Through independent reviews by the three guest editors, who scored proposals on the basis of their quality as well as their fit with the aims of the special issue, and through an extended discussion of the abstracts amongst the co-editors, papers which were found to be particularly promising for achieving the aims of the special issue were selected. The individual contributions then went through the normal ERSS peer review process before publication here.[3]

In the remainder of this introduction to the special issue we explore five key research themes on policy mixes for energy transitions which emerge in these contributions. For each theme we first lay out its meaning and importance, followed by a summary of the corresponding papers and their contribution to the theme. The themes are policy mix rationales and interdisciplinary foundations, instrument interactions and coordination, designing effective policy mixes, policy mixes for creative destruction, and the role of actors and institutions. In the final section we then summarise the most important implications from the emerging academic work on policy mixes for energy transitions and suggest avenues for future research.

4. Five themes of policy mix research

4.1. Policy mix rationales

As many works in environmental economics and innovation studies have attested, policies intended to promote transitions towards low-carbon energy systems need to address multiple market and system failures [23,16]. While economists tend to focus on traditional market failures such as underinvestment in R & D or negative environmental externalities of greenhouse gas emissions as justifications for policy interventions [61,43], innovation scholars in addition point to the existence of structural and transformational system failures, such as institutional failures or failures regarding the direction of transformation processes [16]. Taken together, these sets of failures provide a strong rationale for policy interventions in the form of policy mixes rather than single instruments as there are no 'silver bullet' instruments which on their own could address all the aspects of these failures [23,29,17]. In this context, several articles in this special issue provide insights into different policy mix rationales found in different energy-related sectors and analyze them from different interdisciplinary perspectives.

The first contribution, **Jacobsson et al.** provides a critical assessment of the policy rationale underpinning policy interventions of the EU Commission in the context of the decarbonisation of the EU energy system. The authors argue that the Commission's approach heavily rests on assumptions it has made about market failures, static efficiency and technology neutrality, which disregard insights from classical economists and others about the non-linear nature of technical change and industrial dynamics. Based on this literature, the authors identify a number of weaknesses in the Commission's approach to policy interventions for transformative changes in energy systems and assess how an innovation system approach with its additional focus on structural and functional processes could provide a complement to existing thought and practices. Based on this approach, the authors draw lessons for how effective mixes of policy instruments can be identified which pay greater attention to dynamic efficiency and the structural build-up of innovation systems. This is illustrated using the case of offshore wind in Sweden for which eight system weaknesses – instead of only the three based on the approach utilized by the EU Commission – were identified, thereby leading to a different mix of policy instruments to that proposed by the commission is required if a transition is to occur.

In the second contribution, **Grubb et al.** bridge the lack of engagement between mainstream innovation economics and evolutionary innovation system approaches. For this, the authors propose a framework that is introduced in three steps: first, three domains of socio-economic decision-making regarding technology innovation and adoption choices are outlined and related to three policy pillars; second, an innovation chain approach is proposed as a simplifying framework supporting the explanation of radical differences in innovation intensities between different sectors; and third, based on this analysis a multiple journeys approach is used to capture the processes which are required for successful innovation in this field – ordered according to levels of decision-making domains. The authors conclude by discussing implications for policy makers regarding instrument mixes for energy transitions, including a recognition of differences in mix designs arising from drawing on the different bodies of literature to inform the analysis.

Finally, **Burke and Stephens** argue that thinking about policy mixes for energy transitions from a very broad energy democracy perspective offers better prospects for achieving transitions compared to traditional energy innovation or climate mitigation efforts because of the explicit focus on desirable social change contained in this perspective. They first derive a set of desired policy goals and intended outcomes from a survey of the literature generated by the energy democracy movement. They then describe and categorise the policy instruments proposed by this literature into a set composed of those affecting regulatory context, financial inclusion measures, economic institutions and new energy system institutions, and assess the extent to which the individual instruments are congruent with the goals of energy democracy. Lastly, they assess whether the instruments constitute a comprehensive policy mix which can be expected to support outcomes considered to be constitutive of an energy democracy vision leading to a sustainable transition. They conclude that the energy democracy approach of resist-reclaim-restructure energy systems offers a comprehensive agenda for advancing renewable energy transitions which brings together moves to push back dominant energy regimes while encouraging their replacement through alternative socio-technical configurations such as locally-owned, distributed generation. They also consider their approach as helpful in informing the design and evaluation of policy mixes for energy transitions.

4.2. Interactions and coordination of policy instruments

The second research theme concerns better understanding and analysis of the specific modalities and outcomes from the interaction and coordination of policy instruments which can be traced back to Gunningham et al.'s [33] seminal work on smart regulation. Research on such instrument interactions has developed into a key line of policy mix research, with energy and climate policy as those policy fields covered most intensively in early work, particularly since the introduction of the EU emission trading system (EU ETS) as a novel, market-based climate policy instrument [35]. Studies in this tradition have analyzed the interaction effects, particularly between the EU ETS and policy instruments promoting renewable energies and energy efficiency [36,37,62,45]. A number of methodological approaches and analytical frameworks have been developed for such interaction analysis [63,64,38] with much of this work focusing on the EU [65,66]. Key questions raised in this research concern how instruments interact, how this can be analyzed, and which recommendations arise for more consistent bundles of instruments which reinforce rather than undermine each other in the pursuit of policy objectives [47]. Two papers in this special issue expand the scope of existing research on such instrument interactions.

In the first contribution **del Rio and Cerdá** provide an assessment of the negative impact of specific instruments and their design features for the promotion of electricity from renewable energy sources (RES-E) on CO_2 prices. For this purpose, the authors propose an analytical framework for evaluating the impact of different instruments (e.g. feed-in

(*footnote continued*)
Research Policy *in 2018.*

[3] To avoid a conflict of interest all submissions with author affiliations of the University of Sussex, including those by two of the three guest editors, were handled by guest editor Michael Howlett.

tariffs, auctions) and design features (e.g. target setting, flexible degression) on the interactions between RES-E support and CO_2 mitigation instruments (emissions trading or carbon tax). Two main evaluation criteria used: the adaptability of targets and instruments (in terms of being able to take into account the expected outcomes of one policy on the design of the other, and make adjustments accordingly) and the effectiveness of the policy intervention (in terms of RES-E deployment and CO_2 emission reductions). The qualitative results show that, while negative interactions can be mitigated through coordination, adaptability depends on the choice of instruments and design features of each tool. The alleged negative impact on CO_2 prices is found to be more likely under quantity-based than under price-based CO_2 mitigation instruments. In contrast, they are more likely with price-based than with quantity-based RES-E support instruments. The authors remind us that the choice of design features critically affects this result, thereby underlining the importance of analysing not only instrument types in a mix but also the specific design of instruments themselves.

While much of the literature on instrument interactions has focused on climate and energy policies in Europe, the contribution by **Duan et al.** moves beyond this limited geographical focus by analysing expected interactions of China's novel national greenhouse gas emissions trading system with other climate and energy policies found in that country. Their empirical analysis rests on expert interviews and provides in-depth insights into the policy processes associated with the design and implementation of China's national ETS as well as other mitigation, energy conservation and renewable energy policies. The analysis finds that mandatory consultation processes have not been able to provide a sufficient degree of coordination between emissions trading and other policies, resulting in a loss of effectiveness and efficiency of policy instruments. A main reason for this observed lack of coordination is shown to be the vested interests of relevant departments and individuals reluctant to reduce their functions in the interests of overall system level efficiency and effectiveness, and/or transitions. They argue that addressing the coordination challenges involved in such transitions requires strong political support and leadership at levels higher than those of the organizations that are to be affected by making the instrument mix more consistent. However, the authors argue that since the opportunity for a more systematic coordination of China's ETS and other relevant policies was missed, for the time being coordination at a technical rather than political level may only be possible for achieving the urgently needed improvements in the policy mix. Duan et al. conclude that the ongoing elaboration of the final design of China's national ETS may offer another chance to reduce potentially negative interactions and thus improve the effectiveness and efficiency of China's climate policy mix.

4.3. Designing effective policy mixes

As these articles suggest, while the analysis of instrument interactions remains an important issue in future research, energy transitions call for much greater attention to be paid to the design of policy mixes and their characteristics [46,30,67,68]. Contemporary policy design studies have placed a great emphasis on better understanding tool portfolios themselves and the processes that create them [69–71,29]. The components of such mixes include policy goals and policy means at various levels of generality [72,73,30].

As set out above, in the policy sciences such portfolios are combinations of policy instruments that are expected to achieve a variety of specific policy objectives [33]. Some instruments may work well with others – as is the case with "self-regulation" set within a regulatory compliance framework [74,75] – while other combinations may not, such as, notably, independently developed subsidies and regulation if they work at cross-purposes to simultaneously reward and constrain certain types of activities or behaviours [76].

Studies in the policy sciences and elsewhere have all increased awareness of the many dilemmas that can appear in the path of effective policy tool or 'toolkit' designs and significantly advanced policy design studies in so doing. These works have, among other things, articulated several principles for policy design to guide policy practice [77–79] and noted that mixes have both a 'horizontal' aspect – having to do with the number of tools and goals being addressed by one level of government – as well as often having a multi-level or 'vertical' governance component [71,40]. Effectively optimizing the choice of instruments in the more complex multi-dimensional mixes requires an additional level of knowledge of instrument-goal interactions and governmental contexts requiring an understanding of both long and short-term processes of policy change.

These subjects became a major topic of investigation within comparative policy studies [80–82] over the past several years. Evidence concerning renewable energy and energy efficiency policy, for example, has revealed that policy packages combining voluntary compliance with command-and-control regulation can be inherently inconsistent, bringing out contradictory responses from targets of these policy combinations [83,84]. This raises several key questions on the design of policy mixes which four papers in this special issue address.

Imbert et al. conduct a comparative analysis of bioeconomy strategies in Germany and Italy with a focus on the bioplastics sector. They argue that the transition away from finite fossil fuels does not only involve changes towards a bio-based economy in the energy sector but also in the manufacturing sector. Their analysis builds on a wide-ranging policy strategy concept which combines attention to both the articulation of policy goals as well as policy instruments with an interest in the processes of policy development and the institutional capacities for policy development and implementation. The paper draws up a continuum of policy strategy formation which ranges from emergent, bottom-up processes of incrementally emerging policy mixes to deliberate, top down strategies formulated by bureaucrats. The authors find that while both countries are considered frontrunners with regard to the development of the bioeconomy, their policy strategies are fundamentally different. Germany is found to have pursued a deliberate, formalized, top-down government strategy with a focus on knowledge development and innovation, while Italy's policy strategy can be considered a more emergent, bottom-up, industry stakeholder driven process with a focus on market development. With regard to the vertical policy mix dimension, the authors argue that linkages between the German and the Italian strategies via policy making processes at the EU level have helped to reinforce the emerging transition to a bio-based economy in Europe. This work shows that it is often possible to have several routes to change and what works in one case may not in another, requiring analysts and designers to have a fine appreciation of the nuances of the policy and governance contexts in which mixes are developed and implemented.

Purkus et al. analyse trade-offs between policy flexibility and stability in the European and German bioenergy mix. They note that promoting innovation in the context of sustainability transitions, emphasizes the importance of combining technology- push and demand-pull instruments in a coordinated policy mix. The design of such policy mixes, however, remains challenging, due to path dependencies, interacting market failures, and uncertainty regarding eventual economic, environmental and societal impacts of innovations. This results in the need for an adaptive and flexible policy design, but at the same time, stable political framework conditions are required to bring about lasting changes in production and consumption behaviour. This paper undertakes an economic assessment of how this trade-off between flexibility and stability has been addressed in practice in the European and German bioenergy policy mix. Based on the theory of second best and new institutional economics, they identify dimensions for assessing whether relevant uncertainties, interactions between market failures and other constraints on first-best policy making have been handled in a rational manner. From the case study, they derive lessons for developing bioeconomy policy mixes, as a further example of a decarbonisation policy mix faced by high uncertainty and complexity.

Rosenow et al. explore the purpose of specific instrument types within the instrument mix regarding specific levels of technological complexity and cost-effectiveness, compared across Europe. The paper uses an existing dataset produced as part of a pan-European effort to understand instrument mixes in 14 EU Member States in the area of energy efficiency. They argue that to meet global climate goals an energy transition is needed. However, energy transitions are complex and long-term processes which require a variety of public policy interventions to steer their direction and speed in order to achieve global climate change mitigation targets. One area where policy support is required is energy efficiency, which offers a high potential for carbon savings. It is widely acknowledged that energy efficiency improvements need to be faster and deeper than is currently the case requiring changes to existing policy instrument mixes to support both those energy efficiency measures that are simple and cost-effective as well as more complex and costly technologies. In other words, policy mixes need to be well-targeted and comprehensive. The issue of comprehensiveness is addressed in terms of technology-specificity and the level of complexity and costliness of energy efficiency measures. Based on the empirical analysis and a segmentation of instrument types and their role in the overall mix, Rosenow et al. illustrate the need for using a comprehensive instrument mix rather than single instruments to promote energy efficiency.

Falcone et al. then contribute to discussions about how to design effective policy mixes for energy transitions by presenting an empirical analysis which identifies the most effective policy combinations to steer a sustainable energy transition. They do so under two alternative crisis scenarios: one in which the economic crisis is worsening with biofuel production dropping significantly, and a second in which the economic crisis is improving. Empirically the authors focus on the Italian biofuel sector and in terms of methodology, use a fuzzy inference simulation and two-step investigation. First, they identify the concepts surrounding the biofuel sector by means of a specifically designed questionnaire and review of the relevant literature. Second, they interview experts to map the casual effect relationships among the concepts. On the basis of this map, they then develop two alternative scenarios and the related most suitable instrument mixes to foster the development of the Italian biofuel sector. Not surprisingly, their findings show that the most effective policy mixes vary across the scenarios and goals pursued by policy makers. Therefore, their contribution supports the need to go beyond a simple one-size-fits-all approach to 'optimal' policy mix design and argues that policy mixes are sensitive to feedback and rebound effects that are very context dependent.

4.4. Policy mixes for creative destruction

Much of the existing work on policy action for fostering energy transitions has focussed on how to promote innovation in low carbon technologies, the deployment of renewable energy or energy efficient technologies or the role of economic instruments such as carbon taxes or trading. This work focuses on innovation and deployment of new technologies but there has been too little work on simultaneously pursuing instruments disincentivising existing high carbon technologies. As set out above, it has been argued in the innovation literature that in the context of transitions, policy mixes aiming at structural change within a sector may need to pursue simultaneously the 'creation' of new energy innovations as well as the 'destruction' of incumbent sociotechnical systems in order to speed up processes of 'creative destruction' [31]. This reflects the initial focus on innovation processes in the work on energy transitions, with less attention being paid to potential destabilisation of existing industries or industrial decline. More recent literature has started to pay more attention to processes of regime destabilisation [85–87] but has not specifically addressed how policy can contribute to such destabilisation processes. With many countries now considering the phase out of carbon-intensive technologies such as internal combustion engines or coal fired electricity generation plants, this topic is also receiving increasing interest from policy makers. The three contributions to this theme in the issue therefore add to an emerging strand of work on the question of which role policies aimed at phasing out undesired high carbon energy technologies or practices can play as part of wider policy mixes to promote energy transitions.

Kivimaa et al. connect the literatures of policy evaluation, policy mixes and sustainability transition. They utilize client-oriented evaluation to examine national policies in Finland from the perspective of the low-carbon buildings transition. They note that in Finland, energy efficiency has traditionally received less focus in energy and climate policy strategies compared to renewable energy. However, since 2007, energy efficiency policies addressing buildings gained force. Sixteen new policy instruments were implemented during 2007–2014 and several revisions were made to the building code energy efficiency requirements. They conduct a client-oriented evaluation of the policy mix from the perspective of a boundary actor—integrated energy service companies—to analyse its potential for facilitating a zero-carbon transition. The findings show a divergence of opinions regarding the policy mix's disruptive influence. Where potentially disruptive policy instruments can be found, their impact is reduced due to incoherence in policy implementation processes. The usability of client-oriented evaluation for policy mix analysis is found to be useful in complementing top-down evaluations of policy mixes.

The contribution by **Rogge and Johnstone** then addresses a gap in analyzing the effect of phase-out policies on the development and diffusion of low-carbon technologies by taking the case of the transition of the German electricity generation system towards renewable energies – the so-called Energiewende. Based on a survey of innovation activities of German manufacturers of renewable power generation technologies conducted in 2014 the authors explore the impact such destabilization policies – most prominently Germany's nuclear phase-out policy – had on technological change in renewable energy technologies. Drawing on descriptive statistics and combining insights from earlier regression analyses the authors find evidence that Germany's nuclear phase-out policy had a positive influence on manufacturers' innovation expenditures for renewable energies and was by far the most influential policy instrument for the further expansion of renewable energy in Germany. The insights resulting from this analysis have important implications for the literature on policy mixes and sustainability transitions regarding the 'flip sides' of innovation and the crucial importance of destabilization policies for unleashing 'destructive creation'.

The final contribution to this theme is by **Martin** who critiques the work of Kivimaa and Kern [31] on creative destruction and introduces the concept of "exnovation" into policy mix analysis. The starting point of the argument is an agreement with Kivimaa and Kern that addressing the flip side of innovation is important for facilitating a move away from fossil fuel based energy systems. However, Martin argues that Kivimaa and Kern's focus on the concept of creative destruction and the destabilisation of current regimes is insufficient, and instead proposes to use the concept of exnovation, defined as the ending of technological trajectories in a deliberate fashion by removing their physical infrastructure. A successful policy mix for energy transitions is argued to require attention to processes of innovation as well as exnovation and their dynamic interplay over time, as also illustrated by Rogge and Johnstone in the case of the German nuclear phase-out. The author argues that this is important as otherwise climate friendly innovations can co-exist alongside unsustainable technologies rather than replacing dominant regimes. Martin applies this innovation-exnovation policy mix concept to an analysis of the German Energiewende where the success of renewable energy deployment is partly overshadowed by the persistence of lignite fuelled power stations with high carbon emissions. The analysis aims to assess what a policy mix equally addressing innovation and exnovation would look like and what barriers designing such a mix might face.

4.5. The role of actors and institutions in shaping energy transition policy mixes

Finally, the last theme in this special issue focuses on the influence of institutions and actors in the development of policy mixes for energy transition. In contrast to the policy design literature which often focuses on 'optimal' policy mixes design considerations and ignores the politics of such design processes, the focus of this theme is on the actors and institutions which influence policy mix development processes. It is therefore closely linked to the literature on the messy, everyday politics of policy processes [58] and the emerging literature on the politics of transition processes [14,88]. Rogge and Reichardt [29] already pointed to the importance of analysing policy processes as part of policy mix analyses but without specific considerations as to how to incorporate actors and institutions into the analysis of such processes. The three contributions on this theme therefore poses the question how a focus on actors and institutional contexts can enable insight into the processes of developing policy mixes for energy transitions and their impacts.

Johnstone et al. focus on the United Kingdom's (UK) 'new policy direction' that has weakened support for renewables and energy efficiency schemes while strengthening promotion of nuclear power and hydraulic fracturing for natural gas ('fracking'). The authors argue that a 'policy apparatus for incumbency' is emerging which strengthens key regime-based technologies while arguably damaging emerging niche innovations. Basing the discussion around the three technology-based cases of renewable energy and efficiency, fracking, and nuclear power, this contribution refers to this process as "destructive recreation". The authors raise questions over the extent to which policymaking in the energy field is not so much driven by stated aims around sustainability transitions, as by other policy drivers such as electoral and partisan politics. Their contribution investigates different 'strategies of incumbency' including 'securitization', 'masking', 'reinvention', and 'capture.' Based on this analysis, Johnstone et al. suggest that analytical frameworks should extend beyond a particular sector, with notions of what counts as a relevant 'policy maker'expanded in order to explore a wider range of nodes and critical junctures as entry points for understanding how relations of incumbency are forged and reproduced in existing policy designs.

The contribution by **Bahn-Walkowiak and Wilts** focuses on the potential impact of different institutional settings on the consistency and coherence of resource efficiency policy mixes across 32 European countries. The analysis draws on Rogge and Reichardt's (2016) conceptualisation of policy mix characteristics and analyses the scope, foci, instruments and institutional responsibilities for resource efficiency as a cross-cutting and multi-facetted policy challenge. They argue that the nature of this policy challenge is such that tackling it requires a mix of different strategies and instruments at different governance levels and coordination across several policy fields. The analysis points to the difficulties of ensuring horizontal as well as vertical policy coherence in this policy field given the often very dispersed institutional responsibilities for resource efficiency (e.g. 20 out of 32 countries have 4 or more involved agencies and 12 out of 32 countries have additional regional structures). The authors argue that significant differences between countries and their approaches in the field of resource efficiency underlines that a stronger emphasis on the institutional set-up is needed to explain why many policy mixes lack strategic coordination.

In the final contribution of this special issue, **Jorgensen et al.** discuss transition dynamics towards a Danish low carbon energy system – and the role of policy mixes therein – through an actor-centred Arena of Development approach. This approach focuses on how path dependencies of socio-technical systems may be challenged when controversies and matters-of-concern produce 'arenas' where established governance configurations and the policies of a socio-technical system are challenged. The authors discuss the historic transitions in relation to four focal areas of Danish attempts to become independent of fossil energy: wind power integration in the energy system, energy savings, biomass, and sustainable means of transport and find that re-organising actor-constellations is central for such arenas and defines their boundaries and the policies employed. The analysis demonstrates the conflicts and mixes of policy actors that have moved transition processes forward, but sometimes also stalled them.

5. Conclusions

By showcasing fifteen novel conceptual and empirical contributions on policy mixes for energy transitions this special issue aims at increasing the visibility of policy mix thinking and analysis in this critical policy field. Given the diversity of contributions we close by discussing some overarching reflections on the most important research implications derived from the emerging academic work on policy mixes for energy transitions and implications for policy mix studies more generally.

First, the contributions to the issue show how existing policy mix research employs different terminologies and concepts drawing on different disciplinary traditions, including environmental economics, policy sciences and innovation studies. As such, fruitful dialogue between the different approaches calls for an explicit positioning of research work in this emerging literature, conceptual clarity and the provision of unambiguous definitions, for example regarding the definition and operationalization of the particularly problematic terms of consistency and coherence [29]. While we see great potential for further interdisciplinary policy mix research, we want to stress that it requires an awareness of potential differences in meanings of key terms and an explicit choice of the most appropriate concepts to use for the respective tasks at hand.

Second, methodologically the contributions also draw on a variety of qualitative and quantitative research methods such as expert interviews, process tracing, case studies and surveys. However, the majority of studies in the field so far still tend to rest on qualitative research methods or are of a conceptual nature. We propose that future research should expand its use of quantitative methods – ideally in mixed method designs – for analysing policy mixes, including novel approaches how to do so. Furthermore, while many studies conduct an elaborate mapping of an existing policy mix and explaining its development, this can leave important questions about the actual real world impacts of such mixes unaddressed. As these impacts are crucial for accelerating energy transitions, future policy mix research should pay greater attention to covering the full range of policy making and implementation processes all the way to uncovering system impacts.

Third, the large majority of empirical policy mix research, including the sectors and topics covered in this special issue, has focused on Europe. While some of the insights generated within these studies can arguably also be of relevance beyond this narrow geographical scope, this transferability is limited due to different contexts in other regions of the world. Therefore, future research should expand its geographical scope. In addition, while many of the contributions here, and elsewhere, focus on national policy mixes, several studies pointed to the relevance of paying greater attention to other governance levels, such as to policy mixes of regions or interaction between national and European policy mixes. Therefore, multi-level policy mixes should be a greater subject of interest for future research in this area.

Finally, we note that the studies presented in this special issue followed a broader conceptualization of policy mixes than has often been the case in past work. This enabled novel insights into the complex interplay of policy mixes and energy transitions to be uncovered. For example, several contributions explored the relevance of a number of policy mix characteristics, such as credibility, coherence or adaptability, in their analysis, thereby enabling insights which go beyond studies pursuing narrow policy mix conceptualizations linked to eliminating or correcting market failures in environmental economics. Another example concerns initial attempts to better understand policy mixes for creative destruction and how they may impact energy

transitions which transcends the more processual work done on policy mixes in the policy sciences. However, the contributions of this special issue only begin to address these phenomena and showcase several promising avenues for future research on policy mixes for governing energy transitions, and for policy mix research more generally. It is thus our hope that this special issue will stimulate diverse future research within the emerging fields of policy mix studies and energy transitions, thereby enabling better informed policy advice.

Acknowledgements

The guest-editing of this special issue has been enabled through the Centre on Innovation and Energy Demand which is funded by the Research Council UK's EUED Programme (grant number EP/K011790/1). This funding is gratefully acknowledged. No new data were created during this study. We sincerely would like to thank all reviewers involved in this special issue for their thoughtful and timely comments which have helped to substantially improve this introduction and all contributions to this special issue.

References

[1] F.W. Geels, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, Res. Policy 31 (8–9) (2002) 1257–1274.
[2] R. Fouquet, The slow search for solutions: lessons from historical energy transitions by sector and service, Energy Policy 38 (11) (2010) 6586–6596.
[3] J. Grin, J. Rotmans, J.W. Schot (Eds.), Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change, Routledge, London, XIX, 397 s, 2010.
[4] J. Meadowcroft, What about the politics? Sustainable development, transition management, and long term energy transitions, Policy Sci. 42 (4) (2009) 323–340.
[5] G. Verbong, D. Loorbach, Governing the Energy Transition: Reality, Illusion or Necessity? Routledge, New York, 2012.
[6] K. Araújo, The emerging field of energy transitions: progress, challenges, and opportunities, Energy Res. Soc. Sci. 1 (2014) 112–121, http://dx.doi.org/10.1016/j.erss.2014.03.002.
[7] F. Kern, K.S. Rogge, The pace of governed energy transitions: agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? Energy Res. Soc. Sci. 22 (2016) 13–17, http://dx.doi.org/10.1016/j.erss.2016.08.016.
[8] C. Kuzemko, M. Lockwood, C. Mitchell, R. Hoggett, Governing for sustainable energy system change: politics, contexts and contingency, Energy Res. Soc. Sci. 12 (2016) 96–105, http://dx.doi.org/10.1016/j.erss.2015.12.022.
[9] B.K. Sovacool, How long will it take?: conceptualizing the temporal dynamics of energy transitions, Energy Res. Soc. Sci. 13 (2016) 202–215, http://dx.doi.org/10.1016/j.erss.2015.12.020.
[10] B.K. Sovacool, F.W. Geels, Further reflections on the temporality of energy transitions: a response to critics, Energy Res. Soc. Sci. 22 (2016) 232–237, http://dx.doi.org/10.1016/j.erss.2016.08.013.
[11] G.C. Unruh, Understanding carbon lock-in, Energy Policy 28 (12) (2000) 817–830.
[12] G. Dosi, Technological paradigms and technological trajectories. A suggested interpretation of the determinants and directions of technological change, Res. Policy 11 (3) (1982) 147–162.
[13] W. Walker, Entrapment in large technology systems: institutional commitment and power relations, Res. Policy 29 (7–8) (2000) 833–846.
[14] J. Meadowcroft, Engaging with the politics of sustainability transitions, Environ. Innovation Societal Transitions 1 (1) (2011) 70–75, http://dx.doi.org/10.1016/j.eist.2011.02.003.
[15] F.W. Geels, Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective, Theory Cult. Soc. 31 (5) (2014) 21–40, http://dx.doi.org/10.1177/0263276414531627.
[16] K.M. Weber, H. Rohracher, Legitimizing research, technology and innovation policies for transformative change: combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework, Res. Policy 41 (6) (2012) 1037–1047, http://dx.doi.org/10.1016/j.respol.2011.10.015.
[17] J.C.J.M. van den Bergh, Disagreement on sustainability policy within the social sciences? Eur. Rev. 24 (01) (2016) 83–88, http://dx.doi.org/10.1017/S1062798715000460.
[18] R. Green, Carbon tax or carbon permits: the impact on generators' risks, Energy J. 29 (3) (2008) 67–89.
[19] A.L. Bristow, M. Wardman, A.M. Zanni, P.K. Chintakayala, Public acceptability of personal carbon trading and carbon tax, Ecol. Econ. 69 (9) (2010) 1824–1837, http://dx.doi.org/10.1016/j.ecolecon.2010.04.021.
[20] IEA, Summing up the Parts, Combining Policy Instruments for Least-Cost Climate Mitigation Strategies, Paris, France, (2011) 1 p..
[21] K.S. Gallagher, A. Grübler, L. Kuhl, G. Nemet, C. Wilson, The energy technology innovation system, Annu. Rev. Environ. Resour. 37 (1) (2012) 137–162, http://dx.doi.org/10.1146/annurev-environ-060311-133915.
[22] A.J. Wieczorek, M.P. Hekkert, Systemic instruments for systemic innovation problems: a framework for policy makers and innovation scholars, Sci. Public Policy 39 (1) (2012) 74–87, http://dx.doi.org/10.1093/scipol/scr008.
[23] P. Lehmann, Justifying a policy mix for pollution control: a review of economic literature, J. Econ. Surv. 26 (1) (2012) 71–97, http://dx.doi.org/10.1111/j.1467-6419.2010.00628.x.
[24] S. Jacobsson, V. Lauber, The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology, Energy Policy 34 (3) (2006) 256–276, http://dx.doi.org/10.1016/j.enpol.2004.08.029.
[25] E. Bruns, D. Ohlhorst, B. Wenzel, J. Köppel, Renewable Energies in Germany's Electricity Market: A Biography of the Innovation Process, Springer, Netherlands, Dordrecht, 2011.
[26] E. Gawel, S. Strunz, P. Lehmann, Germany's energy transition under attack: is there an inscrutable German Sonderweg? Nat. Cult. 8 (2) (2013) 121–133, http://dx.doi.org/10.3167/nc.2013.080201.
[27] K.S. Rogge, P. Johnstone, this issue. Exploring the role of phase-out policies for low-carbon energy transitions: the case of the German Energiewende. Energy Res. Soc. Sci.
[28] K. Reichardt, K. Rogge, How the policy mix impacts innovation: findings from company case studies on offshore wind in Germany, Environ. Innovation Societal Transitions 18 (2016) 62–81, http://dx.doi.org/10.1016/j.eist.2015.08.001.
[29] K.S. Rogge, K. Reichardt, Policy mixes for sustainability transitions: an extended concept and framework for analysis, Res. Policy 45 (8) (2016) 1620–1635, http://dx.doi.org/10.1016/j.respol.2016.04.004.
[30] F. Kern, M. Howlett, Implementing transition management as policy reforms: a case study of the Dutch energy sector, Policy Sci. 42 (4) (2009) 391–408, http://dx.doi.org/10.1007/s11077-009-9099-x.
[31] P. Kivimaa, F. Kern, Creative destruction or mere niche support?: innovation policy mixes for sustainability transitions, Res. Policy 45 (1) (2016) 205–217, http://dx.doi.org/10.1016/j.respol.2015.09.008.
[32] N.A. Braathen, Instrument mixes for environmental policy: how many stones should be used to kill a bird? Int. Rev. Environ. Resour. Econ. 1 (2) (2007) 185–235.
[33] N. Gunningham, P.N. Grabosky, D. Sinclair, Smart Regulation: Designing Environmental Policy, Oxford University Press, Oxford, 1998.
[34] C. Nauwelaers, P. Boekholt, B. Mostert, P. Cunningham, K. Guy, R. Hofer, C. Rammer, Policy Mixes for R & D in Europe, UNU-MERIT, University of Maastricht and United Nations University, 2009.
[35] S. Sorrell, J. Sijm, Carbon trading in the policy mix, Oxf. Rev. Econ. Policy 19 (3) (2003) 420–437.
[36] Pablo del Río González, The interaction between emissions trading and renewable electricity support schemes: an overview of the literature, Mitig. Adapt. Strateg. Glob. Change 12 (6) (2006) 1363–1390.
[37] IEA, Interactions of Policies for Renewable Energy and Climate, Paris, (2011).
[38] N.-A. Spyridaki, A. Flamos, A paper trail of evaluation approaches to energy and climate policy interactions, Renew. Sustain. Energy Rev. 40 (2014) 1090–1107, http://dx.doi.org/10.1016/j.rser.2014.08.001.
[39] K. Flanagan, E. Uyarra, M. Laranja, Reconceptualising the 'policy mix' for innovation, Res. Policy 40 (5) (2011) 702–713, http://dx.doi.org/10.1016/j.respol.2011.02.005.
[40] M. Howlett, J. Vince, P. del Río, Policy integration and multi-level governance: dealing with the vertical dimension of policy mix designs, PaG 5 (2) (2017) 69, http://dx.doi.org/10.17645/pag.v5i2.928.
[41] V. Costantini, F. Crespi, A. Palma, Characterizing the policy mix and its impact on eco-innovation: a patent analysis of energy-efficient technologies, Res. Policy 46 (4) (2017) 799–819, http://dx.doi.org/10.1016/j.respol.2017.02.004.
[42] F. Kern, P. Kivimaa, M. Martiskainen, Policy packaging or policy patching?: the development of complex energy efficiency policy mixes, Energy Res. Soc. Sci. 23 (2017) 11–25, http://dx.doi.org/10.1016/j.erss.2016.11.002.
[43] A.B. Jaffe, R.G. Newell, R.N. Stavins, A tale of two market failures: technology and environmental policy, Ecol. Econ. 54 (2–3) (2005) 164–174, http://dx.doi.org/10.1016/j.ecolecon.2004.12.027.
[44] C. Fischer, Combining policies for renewable energy: is the whole less than the sum of its parts? Int. Rev. Environ. Resour. Econ. 4 (1) (2010) 51–92, http://dx.doi.org/10.1561/101.00000030.
[45] D. Antonioli, S. Borghesi, A. D'Amato, M. Gilli, M. Mazzanti, F. Nicolli, Analysing the interactions of energy and climate policies in a broad policy 'optimality' framework: the Italian case study, J. Integr. Environ. Sci. 11 (3–4) (2014) 205–224, http://dx.doi.org/10.1080/1943815X.2014.962549.
[46] M. Howlett, J. Rayner, Design principles for policy mixes: cohesion and coherence in 'new governance arrangements', Policy Soc. 26 (4) (2007) 1–18, http://dx.doi.org/10.1016/S1449-4035(07)70118-2.
[47] M. Howlett, J. Rayner, Patching vs packaging in policy formulation: assessing policy portfolio design, Polit. Gov. 1 (2) (2013) 170–182, http://dx.doi.org/10.12924/pag2013.01020170.
[48] E. Magro, J.R. Wilson, Complex innovation policy systems: towards an evaluation mix, Res. Policy 42 (9) (2013) 1647–1656, http://dx.doi.org/10.1016/j.respol.2013.06.005.
[49] M. Guerzoni, E. Raiteri, Demand-side vs. supply-side technology policies: hidden treatment and new empirical evidence on the policy mix, Res. Policy 44 (3) (2015) 726–747, http://dx.doi.org/10.1016/j.respol.2014.10.009.
[50] R. Quitzow, Assessing policy strategies for the promotion of environmental technologies: a review of India's National Solar Mission, Res. Policy 44 (1) (2015) 233–243, http://dx.doi.org/10.1016/j.respol.2014.09.003.
[51] U. Cantner, H. Graf, J. Herrmann, M. Kalthaus, Inventor networks in renewable energies: the influence of the policy mix in Germany, Res. Policy 45 (6) (2016) 1165–1184, http://dx.doi.org/10.1016/j.respol.2016.03.005.
[52] S. Borrás, C. Edquist, The choice of innovation policy instruments, Technol.

Forecasting Soc. Change 80 (8) (2013) 1513–1522, http://dx.doi.org/10.1016/j.techfore.2013.03.002.
[53] K. Reichardt, S.O. Negro, K.S. Rogge, M.P. Hekkert, Analyzing interdependencies between policy mixes and technological innovation systems: the case of offshore wind in Germany, Technol. Forecasting Soc. Change 106 (2016) 11–21, http://dx.doi.org/10.1016/j.techfore.2016.01.029.
[54] E. Uyarra, P. Shapira, A. Harding, Low carbon innovation and enterprise growth in the UK: challenges of a place-blind policy mix, Technol. Forecasting Soc. Change 103 (2016) 264–272, http://dx.doi.org/10.1016/j.techfore.2015.10.008.
[55] E. Magro, M. Navarro, J.M. Zabala-Iturriagagoitia, Coordination-mix: the hidden face of STI policy, Rev. Policy Res. 31 (5) (2014) 367–389, http://dx.doi.org/10.1111/ropr.12090.
[56] K. Reichardt, K.S. Rogge, S.O. Negro, Unpacking policy processes for addressing systemic problems in technological innovation systems: the case of offshore wind in Germany, Renew. Sustain. Energy Rev. 80 (2017) 1217–1226, http://dx.doi.org/10.1016/j.rser.2017.05.280.
[57] M. Howlett, What is a policy instrument? Tools, mixes and implementation styles, in: P. Eliadis, M.M. Hill, M. Howlett (Eds.), Designing Government – From Instruments to Governance, McGill-Queen's University Press, Canada, 2005, pp. 31–50.
[58] P.A. Sabatier, C.M. Weible, Theories of the Policy Process, 3rd ed., Westview Press, Boulder, CO, 2014.
[59] L. Den Hertog, S. Stroß, Policy coherence in the EU system: concepts and legal rooting of an ambiguous term, Paper Presented at the Conference The EU as Global Player 7–8 April 2011, University Institute for European Studies, Madrid, 2011.
[60] M. Nilsson, T. Zamparutti, J.E. Petersen, B. Nykvist, P. Rudberg, J. McGuinn, Understanding policy coherence: analytical framework and examples of sector-environment policy interactions in the EU, Environ. Policy Gov. 22 (6) (2012) 395–423, http://dx.doi.org/10.1002/eet.1589.
[61] K. Rennings, Redefining innovation – eco-innovation research and the contribution from ecological economics, Ecol. Econ. 32 (2) (2000) 319–332, http://dx.doi.org/10.1016/S0921-8009(99)00112-3.
[62] K. Palmer, A. Paul, M. Woerman, D. Steinberg, Federal policies for renewable electricity: impacts and interactions, Energy Policy 39 (7) (2011) 3975–3991.
[63] V. Oikonomou, C. Jepma, A framework on interactions of climate and energy policy instruments, Mitig. Adapt. Strateg. Glob. Change 13 (2) (2008) 131–156, http://dx.doi.org/10.1007/s11027-007-9082-9.
[64] P. del Río, On evaluating success in complex policy mixes: the case of renewable energy support schemes, Policy Sci 47 (3) (2014) 267–287, http://dx.doi.org/10.1007/s11077-013-9189-7.
[65] P. del Río, Interactions between climate and energy policies: the case of Spain, Clim. Policy 9 (2) (2009) 119–138.
[66] J. Rosenow, T. Fawcett, N. Eyre, V. Oikonomou, Energy efficiency and the policy mix, Build. Res. Inf. 44 (5-6) (2016) 562–574, http://dx.doi.org/10.1080/09613218.2016.1138803.
[67] M. Howlett, R.P. Lejano, Tales from the Crypt: the rise and fall (and rebirth?) of policy design, Adm. Soc. 45 (3) (2013) 357–381, http://dx.doi.org/10.1177/0095399712459725.
[68] M. Howlett, From the 'old' to the 'new' policy design: design thinking beyond markets and collaborative governance, Policy Sci. 47 (3) (2014) 187–207, http://dx.doi.org/10.1007/s11077-014-9199-0.
[69] C. Hood, H. Margetts, The Tools of Government in the Digital age, Palgrave Macmillan, Basingstoke, 2007.
[70] M. Howlett, Designing Public Policies: Principles and Instruments, Routledge, Abingdon, Oxon, New York, 2011.
[71] M. Howlett, Y.P. How, P. del Rio, The parameters of policy portfolios: verticality and horizontality in design spaces and their consequences for policy mix formulation, Environ. Plann. C 33 (5) (2015) 1233–1245, http://dx.doi.org/10.1332/147084414X13992869118596.
[72] B. Cashore, M. Howlett, Punctuating which equilibrium?: understanding thermostatic policy dynamics in Pacific Northwest Forestry, Am. J. Polit. Sci. 51 (3) (2007) 532–551, http://dx.doi.org/10.1111/j.1540-5907.2007.00266.x.
[73] M. Howlett, Governance modes, policy regimes and operational plans: a multi-level nested model of policy instrument choice and policy design, Policy Sci. 42 (1) (2009) 73–89, http://dx.doi.org/10.1007/s11077-009-9079-1.
[74] M.J. Trebilcock, C.J. Tuohy, A.D. Wolfson, Professional Regulation: A Staff Study of Accountancy, Architecture, Engineering and Law in Ontario Prepared for the Professional Organizations Committee, Ministry of the Attorney General, Toronto, 1979.
[75] P.N. Grabosky, Green markets: environmental regulation by the private sector, Law Policy 16 (4) (1994) 419–448, http://dx.doi.org/10.1111/j.1467-9930.1994.tb00132.x.
[76] H. Yi, R.C. Feiock, Policy tool interactions and the adoption of state renewable portfolio standards, Rev. Policy Res. 29 (2) (2012) 193–206, http://dx.doi.org/10.1111/j.1541-1338.2012.00548.X.
[77] H. Doremus, A policy portfolio approach to biodiversity protection on private lands, Environ. Sci. Policy 6 (3) (2003) 217–232, http://dx.doi.org/10.1016/S1462-9011(03)00036-4.
[78] T. Sterner, J. Coria, Policy Instruments for Environmental and Natural Resource Management, RFF Press, 2011.
[79] E.-H. Klijn, J. Koppenjan, Governance network theory: past, present and future, Policy Polit. 40 (4) (2012) 587–606, http://dx.doi.org/10.1332/030557312X655431.
[80] Y. Hou, G.A. Brewer, Substitution and supplementation between co-functional policy instruments: evidence from state budget stabilization practices, Public Adm. Rev. 70 (6) (2010) 914–924, http://dx.doi.org/10.1111/j.1540-6210.2010.02223.x.
[81] B. Kiss, C.G. Manchón, L. Neij, The role of policy instruments in supporting the development of mineral wool insulation in Germany, Sweden and the United Kingdom, J. Clean. Prod. 48 (2013) 187–199, http://dx.doi.org/10.1016/j.jclepro.2012.12.016.
[82] O. Lecuyer, P. Quirion, Can uncertainty justify overlapping policy instruments to mitigate emissions? Ecol. Econ. 93 (2013) 177–191, http://dx.doi.org/10.1016/j.ecolecon.2013.05.009.
[83] P.G.M. Boonekamp, Actual interaction effects between policy measures for energy efficiency – a qualitative matrix method and quantitative simulation results for households, Energy 31 (14) (2006) 2848–2873.
[84] P. del Río, A. Calvo Silvosa, G. Iglesias Gómez, Policies and design elements for the repowering of wind farms: a qualitative analysis of different options, Energy Policy 39 (4) (2011) 1897–1908, http://dx.doi.org/10.1016/j.enpol.2010.12.035.
[85] K. Karltorp, B.A. Sandén, Explaining regime destabilisation in the pulp and paper industry, Environ. Innovation Soc. Transitions 2 (2012) 66–81, http://dx.doi.org/10.1016/j.eist.2011.12.001.
[86] B. Turnheim, F.W. Geels, Regime destabilisation as the flipside of energy transitions: lessons from the history of the British coal industry (1913–1997), Energy Policy 50 (2012) 35–49, http://dx.doi.org/10.1016/j.enpol.2012.04.060.
[87] B. Turnheim, F.W. Geels, The destabilisation of existing regimes: confronting a multi-dimensional framework with a case study of the British coal industry (1913–1967), Res. Policy 42 (10) (2013) 1749–1767, http://dx.doi.org/10.1016/j.respol.2013.04.009.
[88] F. Avelino, J. Grin, B. Pel, S. Jhagroe, The politics of sustainability transitions, J. Environ. Policy Plann. 18 (5) (2016) 557–567, http://dx.doi.org/10.1080/1523908X.2016.1216782.
[89] S. Sorrell, A. Smith, R. Betz, R. Walz, C. Boemare, P. Quirion, J. Sijm, D.M.P. Konidari, S. Vassos, D. Haralampopoulos, C. Pilinis, Interaction in EU Climate Policy: Final Report, SPRU, Brighton, 2003.
[90] K. Thelen, How institutions evolve: Insights from comparative historical analysis, in: J. Mahoney, D. Rueschemeyer (Eds.), Comparative historical analysis in the social sciences, Cambridge University Press, Cambridge, 2003, pp. 208–240 Chapter 6.
[91] J. Markard, R. Raven, B. Truffer, Sustainability transitions: An emerging field of research and its prospects, Res. Policy 41 (6) (2012) 955–967.
[92] M. Howlett, Y.P. How, P. del Rio, The parameters of policy portfolios: verticality and horizontality in design spaces and their consequences for policy mix formulation, Environ. and Planning C: Government and Policy 33 (5) (2015) 1233–1245.