Research Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Research Policy

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

The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions

Duncan L. Edmondson[a,*], Florian Kern[a], Karoline S. Rogge[a,b]

[a] SPRU—Science Policy Research Unit, Jubilee Building, University of Sussex, Brighton, BN1 9SL, UK
[b] Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI), Breslauer Straße 48, 76139 Karlsruhe, Germany

ARTICLE INFO

Keywords:
Policy mix
Sustainability transitions
Policy processes
Policy feedback
Socio-technical system

ABSTRACT

Understanding how policymaking processes can influence the rate and direction of socio-technical change towards sustainability is an important, yet underexplored research agenda in the field of sustainability transitions. Some studies have sought to explain how individual policy instruments can influence transitions, and the politics surrounding this process. We argue that such individual policy instruments can cause wider feedback mechanisms that influence not only their own future development, but also other instruments in the same area. Consequently, by extending the scope of analysis to that of a policy mix allows us to account for multiple policy effects on socio-technical change and resultant feedback mechanisms influencing the policy processes that underpin further policy mix change. This paper takes a first step in this regard by combining policy studies and innovation studies literatures to conceptualise the co-evolutionary dynamics of policy mixes and socio-technical systems. We focus on policy processes to help explain how policy mixes influence socio-technical change, and how changes in the socio-technical system also shape the evolution of the policy mix. To do so we draw on insights from the policy feedback literature, and propose a novel conceptual framework. The framework highlights that policy mixes aiming to foster sustainability transitions need to be designed to create incentives for beneficiaries to mobilise further support, while overcoming a number of prevailing challenges which may undermine political support over time. In the paper, we illustrate the framework using the example of the zero carbon homes policy mix in the UK. We conclude with deriving research and policy implications for analysing and designing dynamic policy mixes for sustainability transitions.

1. Introduction

Understanding the role of policy processes in influencing the rate and direction of sustainability transitions remains a fundamental challenge in the existing literature on socio-technical transitions (Markard et al., 2012). Scholars in this field have sought to facilitate the restructuring of socio-technical systems towards more sustainable ways of fulfilling societal needs (Geels 2002, 2004). Moving towards more sustainable configurations requires significant structural changes in existing systems, often instigated by policy to reconfigure market selection environments, user preferences and cultural perceptions (Geels et al., 2016). Policy action is argued to be required to overcome various market and system failures (Weber and Rohracher, 2012).

However, 'behind policy there is always politics' (Meadowcroft, 2011: 73) and political negotiations can have a major influence on the stability or change of policy, which in turn influences socio-technical developments. It has been argued that policy stability is beneficial in creating positive expectations of a path to commercialization for early stage technologies (Foxon et al., 2005). However, it has also been argued that policy needs to be able to account for changes in the socio-technical system, incorporating enough flexibility to allow for revisions without deterring investor confidence (Hekkert et al., 2007). Due to the long timeframes involved in sustainability transitions, the types of policy instruments aimed to foster transitions may change significantly over time to address changing objectives and different stages of innovation (Turnheim et al., 2015). The ways in which policy mixes evolve over time can have a significant influence on the rate and direction of sustainability transitions (Reichardt et al., 2016). Collectively, these considerations highlight that in the context of sustainability transition processes, it is important not only to study the content of policy instruments (e.g. what level of support is provided for which technology?), but the processes through which instruments are introduced, adapted or kept stable over time.

Another challenge in understanding the influence of policy on sustainability transitions is the need to move beyond a focus on single policy instruments towards wider policy mixes (Rogge et al., 2017).

* Corresponding author.
E-mail address: d.edmondson@sussex.ac.uk (D.L. Edmondson).

https://doi.org/10.1016/j.respol.2018.03.010
Received 24 April 2017; Received in revised form 1 March 2018; Accepted 13 March 2018

Contributions from various literatures, including innovation studies (Nauwelaers et al., 2009), environmental economics (Lehmann, 2010) and policy analysis (Howlett and Rayner, 2007), have already sought to explore important aspects of policy mixes; such as the design features of individual instruments in the mix (Kemp and Pontoglio, 2011), instrument interactions (del Río González, 2006; Nauwelaers et al., 2009), the elements of the mix (Borrás and Edquist, 2013), the policy strategy (Quitzow, 2015a), as well as overall characteristics of mixes (Howlett and Rayner, 2013; Reichardt and Rogge, 2016) and policy processes (Flanagan et al., 2011). Sustainability transitions are complex, multi-faceted processes, involving long time frames, multiple actors, and often a range of both competing and complementary technologies (Geels, 2004). Such complexity means that no single approach, technology, intervention or policy instrument is capable of achieving transformative change, often resulting in large numbers of policy instruments being implemented over time to address multiple objectives (Loorbach, 2010; Kern and Howlett, 2009; Kern et al., 2017a, 2017b).

Recently, scholars have called for an integration of these perspectives into the study of sustainability transitions, to produce more meaningful analytical insights and policy recommendations (Rogge and Reichardt, 2016). This paper follows suggestions of Flanagan et al. (2011) and Rogge and Reichardt (2016) to take a first step towards better conceptualising the role of policymaking processes in the co-evolution of policy mixes and socio-technical change. Only few studies have started to draw on policy process theories in the context of transitions to better understand processes of policy change (Kern and Rogge, 2017). Others have sought to analyse how single policies co-evolve with the socio-technical system (Hoppmann et al., 2014), but only present a relatively simplistic conceptualisation of the policy process. We complement these early attempts by paying greater attention to how policymaking processes influence the co-evolution of policy mixes and socio-technical systems. We do so by drawing on the policy feedback literature from the field of policy sciences (Pierson, 1993).

The policy feedback literature draws attention to the continuous interactions between public policy, the outcomes in society, and how these outcomes affect policy actors in ways that influences politics and subsequent policymaking (Weible, 2014:13). We suggest this analytical focus offers important insights to explain the dynamic and recursive nature of how policy mixes and socio-technical systems co-evolve. Our proposed framework aims to explore how policy mixes stimulate changes in socio-technical systems through policy effects, and how these changes can subsequently generate feedback mechanisms influencing the evolution of the policy mix. The paper is predominantly a conceptual contribution developing a novel framework, but uses the zero carbon homes policy mix in the UK as an empirical illustration to help highlight interactions dynamics of the framework. This seems a particularly well suited example as it represents an instance where an ambitious policy target lost political support over time due to a range of policy effects and feedback mechanisms, ultimately leading to its abandonment.

The remainder of the paper is structured as follows. In section 2, we review two emerging strands of research exploring the role of policy in sustainability transitions: section 2.1 reviews work on policy, politics and policy processes within sustainability transitions, while section 2.2 reviews the development of policy mix thinking and its application to sustainability transitions. In section 3, we review concepts from the policy feedback literature and in section 4 utilise these ideas to conceptualise the co-evolution of policy mixes and socio-technical change for sustainability transitions. To illustrate interaction dynamics of the framework, section 5 draws on the zero carbon homes policy mix in the UK. In section 6 we derive conclusions, suggest avenues for further research and policy mix design considerations for sustainability transitions.

2. Sustainability transitions, politics and policy mixes

'Socio-technical systems' are commonly understood as the "linkages between elements necessary to fulfil societal functions" (Geels, 2004, 900), such as energy, transport, housing and food production and consumption. Such a system consists of multi-faceted combination of actors, networks, institutions, artefacts, infrastructure, markets and practices along with cultural and symbolic views and representations (Geels, 2004). A socio-technical transition is a combination of processes leading to a fundamental shift of a socio-technical system (Geels and Schot, 2010). Transitions involve technological, organisational, institutional, political, and socio-cultural changes (Markard et al., 2015). Changes to any of these aspects can produce systemic effects, due to their interactions with other components of the socio-technical system (Foxon, 2011). However, reconfigurations do not happen autonomously and require the activities of human actors (Geels, 2004: 900).

Historical examples of transitions include the shift from sailing ships to steamboats (Geels, 2002), and from horse-driven carriages to automobiles (Geels, 2005). Studies of such examples highlight that transitions have historically taken long periods of time (25–50 years) to unfold (Geels and Schot, 2007). Yet, some more recent transitions have been shown to occur quicker (Sovacool, 2016) and there is a live discussion about whether sustainability transitions can occur more quickly if they are consciously governed, while most historical transitions were emergent, market-driven processes (Kern and Rogge, 2016). This is indeed the ambitious foundational claim of much thinking in the sustainability transitions literature, that it is possible to influence the speed and direction of socio-technical transitions towards sustainability and that public policy can play a key role in this regard.

One of the main challenges in this field therefore is to improve the understanding of how policies can influence transitions (Markard et al., 2012). In the following sections, we review two areas of development within the literature that have sought to address this challenge: first the role of policy, politics and policy processes in sustainability transitions and second the growing interest in considering policy mixes rather than single instruments.

2.1. Policy, politics and policy processes in sustainability transitions

Policy is widely considered as an integral constituent of transitions towards sustainability (Jacobsson and Lauber, 2006) and is argued to help accelerate the pace of transitions (Kern and Rogge, 2016). One important policy to change selection environments towards more sustainable configurations, is to internalise the external costs of environmental damage, either through carbon pricing or cap and trade schemes (Baranzini et al., 2017). Early advocates of transition management proposed the use of such 'control policies' as part of efforts to promote transitions (Kemp and Rotmans, 2004). However, beyond internalising the market failure of environmental externalities, a number of structural and transformational system failures have been identified which also require policy intervention (Weber and Rohracher, 2012; Wieczorek and Hekkert, 2012). In this regard, policymakers can implement policies to stimulate transitions, including subsidies, procurement, R&D grants, and upskilling and training incentives (Markard et al., 2015).

More specifically, the Strategic Niche Management (SNM) literature suggests that policymakers need to create protective spaces to shield and nurture sustainable innovations; and to make mainstream market conditions more favourable to emergent technologies (Smith and Raven, 2012; Raven et al., 2016). In addition, the Transitions Management literature stresses the importance of 'transition arenas' to bring together frontrunners to create new networks and accelerate learning and technological development (Kemp and Rotmans, 2004). It has also been stressed that experiments should be complemented with long term agenda setting to help establish a shared vision to guide investment and reduce uncertainty (Rotmans and Loorbach, 2010).

Transition scholars suggest that a constant realignment of policy with the changing conditions of the socio-technical system is necessary (Hoppmann et al., 2014), requiring reflexive policymaking and learning over time to account for the unpredictable nature of transitions (Rotmans and Loorbach, 2010). Equally, policy change can impact resource availability, investor confidence, or signal changes in political will. Accordingly, not only changes in policy content, but also the process through which policy changes, can have impacts on the socio-technical system (White et al., 2013; Reichardt et al., 2017). Consequently, over time policy changes can lead to virtuous or vicious cycles of causation influencing the momentum of sustainability transitions (Hekkert et al., 2007).

So far, the transitions literature has typically referred to the content of policymaking in terms of objectives, programs, regulations, laws and resource allocations (Markard et al., 2015). Moving beyond the content of policies, "[p]olitics refers to the procedural dimension of policymaking, with a variety of actors negotiating and interacting to produce public policies" (Markard et al., 2014: 4). Policymaking can be understood as the design, implementation, adaptation and discontinuation of public policies (Sabatier and Weible, 2014). This can be considered as the process of implementing overarching objectives, and is heavily influenced by the political conditions. States are dependent on prevailing economic structures and industries, which can create vested interests as political and economic actors become entangled, often resulting in a high level of influence of incumbent actors on policy decisions (Meadowcroft, 2011; Johnstone et al., 2017).

A number of contributions have already sought to help analyse the politics of transitions (Baker et al., 2014; Meadowcroft, 2009; Meadowcroft and Langhelle, 2009; Shove and Walker, 2007). Studies have for example focused on the way in which ideas are presented (Kern, 2011; Scrase and Smith, 2009), the role of coalitions (Hess, 2014, 2015; Markard et al., 2015), power relations (Avelino and Rotmans, 2009; Avelino, 2011; Geels, 2014), and policy networks (Normann, 2017). To conceptualise how politics influences policymaking processes, transition scholars have started to integrate insights from prominent policy process theories, including Sabatier's Advocacy Coalition Framework (Markard et al., 2015), Kingdon's Multiple Streams (Normann, 2015), and Marsh's Policy Networks Approach (Normann, 2017). From these contributions, we know that during transition processes windows of opportunity can allow actors to advocate certain technologies and gain favourable policy outputs. Yet, over time, changing conditions can cause these windows to close and policy support to be withdrawn (Normann, 2015). Similarly, beliefs of actors can change over time, which may influence participation in coalitions (Markard et al., 2015) and the formation of policy networks (Normann, 2017).

Some contributions have also explored linking policy processes to the rate and direction of change in the socio-technical system more directly. Hoppmann et al. (2014) highlight the iterative process of policy realignment for solar PV in Germany, responding to the changing conditions within the socio-technical system. Lauber and Jacobsson (2016) also follow the evolution of the German Feed-in-Tariff (FiT), focussing on the politics surrounding the empowerment of niche actors and how changes in the socio-technical system over time influenced discourses of different actor groups. These papers highlight policy change in response to changes in the socio-technical system, but their conceptualisations of policymaking processes is underdeveloped. Furthermore, these papers only cover a single policy instrument and its revisions over time, rather than a wider policy mix.

Consequently, the interplay of technological change, politics and policy processes remains understudied (Schmidt and Sewerin, 2017) and under conceptualised, particularly when considering collections of policies that make up an overarching policy mix. In the following, we therefore review the emerging literature on policy mixes in the field of sustainability transitions.

2.2. Policy mixes and sustainability transitions

Recently, there has been increased attention to policy mixes in innovation studies (Flanagan et al., 2011; Guerzoni and Raiteri, 2015). Scholars of sustainability transitions also, have argued to extend the scope of analysis beyond individual instruments to that of broader policy mixes (Rogge and Reichardt 2016). Sustainability transitions exhibit several characteristics that make the policy mixes required to foster transitions distinct, and arguably more challenging than in other areas. This is not only due to a number of interrelated market and system failures (Foxon et al., 2005; Weber and Rohracher, 2012) but also due to the required speed and unprecedented scale and complexity of the required changes.

Two particular challenges concern destabilization and accumulation. Regarding the former, scholars have argued that policy mixes for sustainability transitions need to actively seek to destabilise the existing configuration to speed up transitions (David, 2017; Rogge and Johnstone, 2017; Kivimaa and Kern, 2016). Regarding the latter, policies to support sustainability transitions are commonly added to the mix alongside existing policies (often supporting the regime) rather than replacing them (Kern and Howlett, 2009; Kern et al., 2017a, 2017b). This can limit the transformative potential of policy mixes for sustainability transitions and produce complex combinations of interacting instruments leading to unintended or undesirable effects.

Given these challenges, Rogge and Reichardt (2016) propose a framework for analysing policy mixes for sustainability transitions. They argue that it is important to not only look at interacting instruments but also to consider policy strategies as elements of a policy mix. We follow this conceptualisation, thereby acknowledging the need for long-term strategies for guiding transitions (Foxon and Pearson, 2008; Weber and Rohracher, 2012), which are considered separately from the instrument mix[1] (Fig. 1).

Drawing on insights from the policy design and innovation literatures they also stress that policy mix characteristics, such as the consistency of the instrument mix with stated policy objectives, may help explain the impact of policy mixes (see also Kern and Howlett, 2009; Alkemade et al., 2011). In line with Flanagan et al. (2011), they also call for increased attention to the underlying "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" (Rogge and Reichardt, 2016, 1625).

Our contribution focusses on these policy processes, specifically on the effects of policy decisions on socio-technical systems, and the resultant influence of these changes on the further evolution of the policy

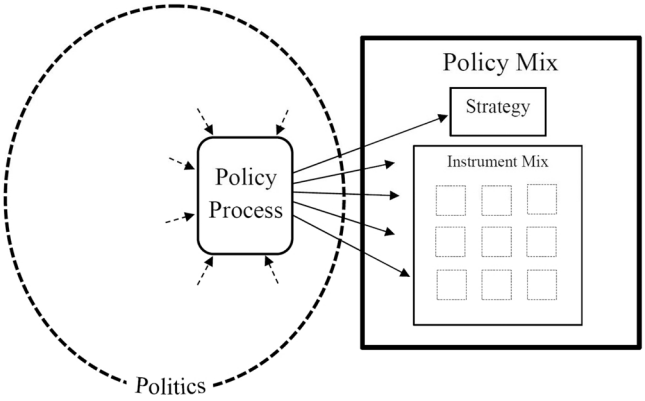

Fig. 1. Politics, Policy Processes and Policy Mixes in Sustainability Transitions.

[1] This is an important distinction as much of the policy mix literature uses 'instrument mix' and 'policy mix' interchangeably.

mix (Section 4). In order to develop a conceptual framework for studying these processes, we draw on the policy feedback literature (Pierson, 1993) which we review in the following section.

3. Analysing policy processes: insights from the policy feedback literature

To address the call for a more explicit consideration of policy processes in the field of sustainability transitions we apply insights from the Policy Feedback literature (Pierson, 1993). We have chosen to build on this approach for four reasons.

First, this literature addresses the interdependencies between policies and further policymaking. It investigates how the effects of a policy change alter subsequent rounds of policymaking, which makes it well suited to our focus on the co-evolution of policy mixes and socio-technical change. Secondly, in the transitions literature technological and institutional co-evolution has been used to partly explain 'carbon lock-in' (Foxon, 2011; Unruh, 2000). We suggest that the policy feedback literature with its attention to path dependency (Pierson, 2004) can contribute to our understanding of such lock-in processes. Third, policy feedback thinking has epistemological similarities to the transitions literature. Both approaches have conceptual roots derived from the punctuated equilibrium paradigm (Gould and Eldredge, 1977). Each propose that revolutionary change happens in cycles, where disruption of a stable system leads to a period of radical change, which re-stabilises over time to reach a new equilibrium. Finally, within the feedback literature some authors have focused on single policy instruments (Jordan and Matt, 2014), while others have already drawn attention to the importance of considering several instruments (Weaver, 2010; Oberlander and Weaver, 2015). Consequently, the latter strand particularly lends itself to our purpose.

The policy feedback literature has its roots in historical institutionalism and rational choice (Pierson, 1993, 2004), and has more recently integrated insights from punctuated equilibrium theory (Jacobs and Weaver, 2015; Patashnik and Zelizer, 2013). It explores mechanisms through which policies reshape social and state actors' interests and capacities over long periods of time in ways that change the prospects for the policies' future maintenance, expansion, or reversal (Skocpol, 1992). The core argument in this literature is that policies are not merely the products of politics, but also influence politics through societal reconfigurations. Policy alters state capacities, it changes incentives for collective action, and encourages social adaptations that may become difficult to reverse (Patashnik and Zelizer, 2013).

In Pierson's (1993) seminal work he identified ways in which policy design can incentivise actors to participate in policymaking processes and shape the political conditions. This early literature seeks to explain the influence of policy through two factors: 'resource effects' (policies as packages of resources that affect interest groups, state capacities and mass publics), and 'interpretive effects' (policies as sources of information that affect patterns of cognition, understanding and meaning) (Mettler and Soss, 2004: 60). Patashnik and Zelizer (2013) built upon these effects, drawing attention to the institutional supports that may limit the capacity of a policy to create positive feedback. They argue that failure to uproot institutional arrangements, or layering new policy alongside existing arrangements, can generate conflicts among programs and agencies which undermines policy support. Consequently, *layering* is considered much less effective for institutional recalibration than *dismantling* (terminating the existing arrangements) (Patashnik and Zelizer, 2013: 1077).

Recent scholarship has highlighted that these effects (resource, interpretive and institutional) are better termed 'feed-forward' effects, as they describe post-enactment policy consequences with no complete feedback loop (Schneider and Ingram, 2009: 103; Jordan and Matt, 2014: 231). These effects "show the feed but not the back (or they just assume the back)" (Campbell, 2012: 347). Therefore, following the suggestions of Jordan and Matt (2014), we move towards a conceptualisation of complete feedback loops making a distinction between the forward and backward dimension of feedback processes. We refer to the effects of policymaking on the socio-technical system as the '*policy effects*' and the resultant influence of the socio-technical system on future policymaking as the '*feedback mechanisms*' (see section 4.1–4.2).

Policies are not thought to automatically generate feedbacks mechanisms, but require coalitions of actors to take political action for the effect of a given policy to influence further policy processes (Pierson, 1993, 2000). Scholars have conceptualised various feedback mechanisms, including influence on interest groups, altering of administrative capacities of the state (state-building), and changes in political participation (Pierson, 1993; Mettler, 2002; Béland, 2010). In a recent contribution from Oberlander and Weaver (2015), feedback mechanisms are conceptualised into three broad categories: *socio- political*, *fiscal* and *administrative* (see section 4.2 for details). We draw on this contribution as it is the most fully realised conceptualisation of feedback mechanisms to date, while it responds to two criticisms of the existing literature.

First, much feedback literature has narrowly focussed on the occurrence of positive feedback, and has been increasingly criticised for over-determinism (Béland, 2010). The underlying assumption of the (positive) feedback literature is that feedbacks will occur, whereby choosing policy alternatives becomes more costly over time, making it increasingly difficult to choose alternatives (Pierson, 1993). Therefore, a recent line of scholarship has highlighted the role of negative feedback, and even suggested that negative feedback may have greater influence on policymaking than positive feedback (Patashnik and Zelizer, 2009, 2013; Weaver, 2010).

Secondly, while scholars have succeeded in providing empirical instances of feedback mechanisms (Pierson, 2007), there had been little progress in translating this into a comprehensive research agenda determining when feedback mechanisms are expected to occur (Patashnik and Zelizer, 2013: 1075). Scholars had sought to explain *how* these feedbacks occurred, but less attention was paid to *if* they occur or the conditions under which they may or may not. Oberlander and Weaver (2015) describe both positive (self-reinforcing) and negative (self-undermining) feedback mechanisms; along with the conditions that would amplify the occurrence of negative feedback mechanisms. Consequently, we draw on these categories in developing our framework.

4. Policy mix feedback in sustainability transitions: towards a conceptual framework

In this section, we develop a novel conceptual framework for analysing the co-evolution of policy mixes and socio-technical systems in processes of sustainability transitions (Fig. 2). More precisely, as transitions unfold through co-evolutionary dynamics of system components, our framework focusses on the co-evolution of the policy mix, as part of the institutional structure of the system, with the other system components including technologies, user dynamics, and business strategies (Foxon, 2011).

The key idea of our co-evolutionary framework is that policy mixes have resource, interpretative and institutional effects on the evolution of the socio-technical system, and that in turn, developments in the socio-technical system influence the policy mix through a range of feedback mechanisms[2] (Fig. 2). These include socio-political, administrative and fiscal feedback mechanisms.

However, rather than influencing the policy mix directly these

[2] As explained in section 3, we distinguish between the forward and backward dimension of policy feedback. We consider the forward dimension as the policy effects of the mix on socio-technical change. We use 'feedback mechanisms' and 'feedbacks' interchangeably throughout the remainder of the paper to capture the backward dimension of policy feedback. Feedback loops capture both the forward and backward dimension of policy feedback, which are explained in section 4.4.

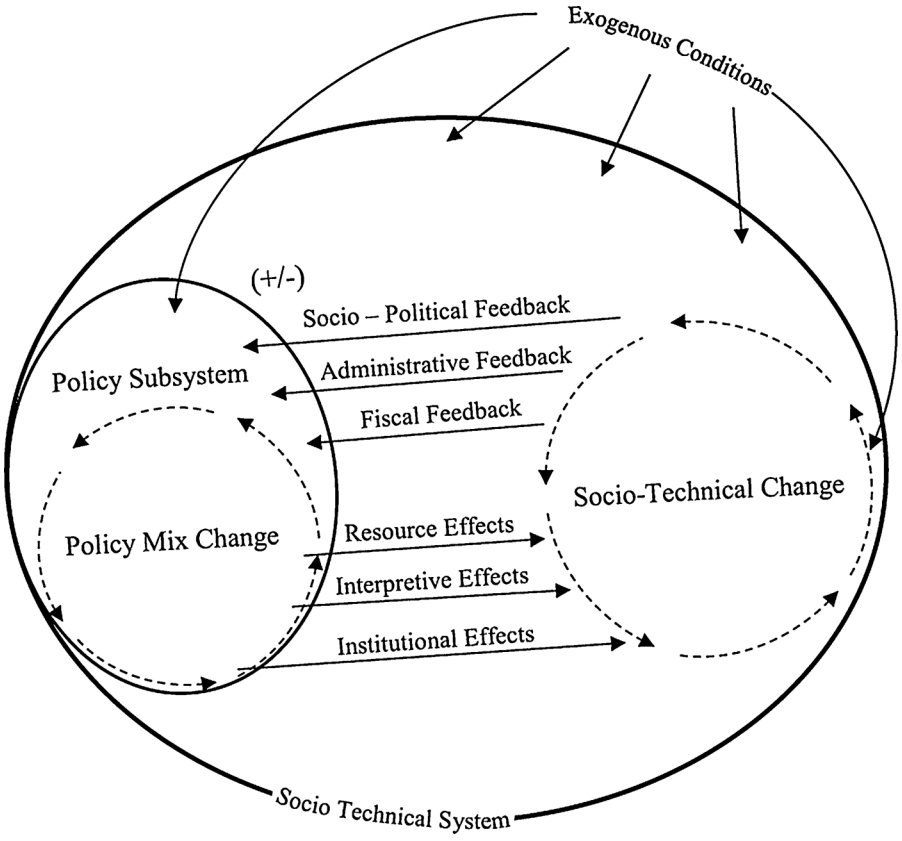

Fig. 2. Dynamic interactions of the policy mix and the rest of the socio-technical system.

feedback mechanisms rather influence the 'policy subsystem'. Such a policy subsystem can be conceptualised as the relationships between actors responsible for policy decisions and 'pressure participants' (Jordan et al., 2004), which include interest groups with which decision makers consult (Cairney and Heikkila, 2014). Thereby, actors play a central role in the framework as the agents of change in both the policy subsystem and in the socio-technical system.

When considering the influence that actors have on the policy process, the implicit assumption in the transitions literature involves a power struggle between niche actors and dominant incumbents. We infer from existing literature that the political influence of actor coalitions is related to their ability to mobilize resources (Hess, 2014; Markard et al., 2015), where resources can be considered "persons, assets, materials or capital, including human, mental, monetary, artefactual and natural resources" (Avelino and Rotmans, 2009: 551). Accordingly, policy processes are characterised through resource interdependencies in which bureaucrats seek information and advice from different interest groups, who exchange information for access to and potential influence within government (Cairney and Heikkila, 2014).

In the following subsections, we develop the conceptual framework in more detail. While we describe each component in turn, these processes often occur simultaneously, where policies create multiple policy effects, and the forms of feedback that occur often influence each other. Consequently, section 4.4 elaborates potential interactions between the various processes covered by the framework.

4.1. Effects of policy mixes on socio-Technical system

The policy mix, with its strategies and various instruments, stimulates change in the socio-technical system through resource, interpretative and institutional effects. These policy effects are determined by choices (intentional or otherwise) regarding design features of individual instruments (such as their level of support), and characteristics of the policy mix (such as its consistency or credibility).

4.1.1. Resource effects

Resource effects are the result of the resources that the policy mix bestows upon target groups (Pierson, 1993; Patashnik and Zelizer, 2009). These resources can influence the rate and direction of transitions. For example, policy mixes can support knowledge creation of low-carbon technologies through R&D (Hekkert et al., 2007), facilitate their demonstration and procurement (Jacobsson and Bergek, 2011), or create favourable market conditions for the diffusion of sustainable solutions (Smith and Raven, 2012). Providing resources can therefore influence the activities and strategies of actors in ways that stimulate changes of the socio-technical system towards sustainability (Foxon, 2011). The magnitude and target actors of resource effects are determined by the design features of individual instruments (e.g. level and duration of support) and interactions with other instruments in the mix (Kemp, 1997; del Río González, 2010; Rogge and Reichardt, 2016).

Sustainability transitions are complex, multi-faceted processes with multiple actors and often involve supporting both complementary and competing technologies (Geels, 2004). Consequently, policy mixes aiming to foster transitions produce multiple resources effects, stimulating hard to predict interactions in the socio-technical system and unintended consequences. This increases as layering of policy mix elements accumulates and as policy instruments act in a changing social, technical and economic context (Jacobs and Weaver, 2015). A policy mix may simultaneously support both niche and regime actors, or policy makers may seek to reduce resource flows to unsustainable regime practices which typically affects incumbents (Kivimaa and Kern, 2016). Consequently, how resources are allocated will not only influence the rate and direction of socio-technical change, but will also incentivise actors to mobilise and support or oppose the policy mix to protect or secure resources.

4.1.2. Interpretive effects

The policy mix also produces interpretive effects, providing information and changing patterns of cognition, understanding and meaning (Pierson, 1993), thereby creating or changing visions and expectations of actors (Jacobsson and Bergek, 2011; Smith and Raven, 2012). This is important in sustainability transitions as actors' perceptions can influence investment decisions and innovative activities (Hekkert et al., 2007; Jacobsson and Bergek, 2011), including: engaging in green R&D (Hekkert et al., 2007), the formation of learning networks (Mourik and Raven, 2006) and advocacy coalitions to lobby for resources for more sustainable alternatives (Bergek et al., 2008).

If actors perceive apparent 'failings' in the design of either individual policy mix elements (strategies and instruments) or the mix as a whole, it can influence stakeholders' opinions of the capabilities of the public sector actors charged with design and implementation of the mix, and/or can be seen as indications of limited political will to achieve policy objectives. For example, a policy strategy to promote sustainable innovation may establish expectations about future resource effects beneficial to niche actors, as it provides guidance and a mandate for the design of individual instruments, as well as the composition of the instrument mix. Yet, if actors perceive instruments as providing insufficient resources to achieve policy objectives, this inconsistency may negatively influence the cognitions of actors regarding the strength of the political will behind the stated policy objectives (Reichardt et al., 2016).

In such instances, policy makers may wish to appear to support an area of development for political benefit (such as electoral payoffs), while being reluctant to devote sufficient resources due to split incentives, close networks between incumbents and state actors or budget constraints (Patashnik and Zelizer, 2009). Consequently, the credibility of the policy mix, i.e. the extent to which it is considered believable and reliable (Rogge and Reichardt, 2016), will influence the perceptions of actors and may have direct effects on their investment decisions (Rogge and Schleich, 2018).

4.1.3. Institutional effects

The institutional structure of the socio-technical system includes laws, rules, and regulations. Accordingly, policy mix change can be considered as part of institutional change. However, the mix will also interact with the wider institutional structure it is situated in, which can influence its effects on socio-technical change, and may limit its capacity to achieve policy objectives. Policy mix change may instigate reconfigurations of these wider aspects of the institutional structure through institutional effects. This may include expanding state capacities to design, implement, and evaluate policies, and to enforce compliance, in order to make the policy mix operational (Patashnik and Zelizer, 2009). This may for example include the capabilities of local authorities to implement national level policy objectives, which may affect their relative success (Patashnik and Zelizer, 2009). An example of such institutional effects would be establishing an autonomous agency capable of launching policy initiatives (Patashnik and Zelizer, 2009).

Similarly, institutional effects can reconfigure aspects of the institutional structure that may otherwise support the regime. These may include replacing the established unsustainable rules embodied in institutions (e.g. legislations), and changing participation in policy networks to involve outsiders (niche actors) in addition to insiders (incumbents) (Kivimaa and Kern, 2016). Policy mixes for sustainability transitions will face the ongoing challenge of maintaining political support if they threaten or impose losses on powerful groups, providing them with motivation for political opposition to protect their interests (Patashnik and Zelizer, 2013). Thus, to support a niche as it scales up requires reforming the institutional structure to protect it, both from processes within the niche that could otherwise de-stabilise it, and against external destabilising processes originating from resistance within the unsustainable regime (Mourik and Raven, 2006). For example, bureaucracies and other public bodies may develop operating procedures that favour certain sources of evidence and some participants over others (Béland, 2010). Failing to reform these arrangements may allow established relationships with regime actors to influence policy decisions, which may negatively influence the rate and direction of transitions.

After having conceptualised how the policy mix has effects on the socio-technical system, the next subsection will discuss how changes in the socio-technical system, in turn, create feedbacks to the policy subsystem.

4.2. Feedback mechanisms

Feedback mechanisms contribute to a reconfiguration of the policy mix over time through socio-political, fiscal and administrative feedbacks. These feedback mechanisms are considered to influence policy-making through different groups of actors active in the policy subsystem. These actors influence the support for the policy mix, which may contribute towards policy mix change. Positive feedbacks can help explain how new policy strategies can become stable and self-reinforcing. Negative feedbacks help explain why opposition against new policy strategies and instruments can result in a loss of political support for policy mix elements. This may result in a reduction or withdrawal of public resources for sustainable alternatives, consequently reducing momentum of transition.

4.2.1. Socio-Political feedback mechanisms

Socio-political feedbacks concern whether public and stakeholder support for a policy mix, or certain components of it, is reinforced or undermined over time. Such socio-political feedback can involve three dimensions: cognitive, constituency and agenda feedbacks.

Cognitive feedbacks contribute to cognitions regarding the effectiveness and/or efficiency of a policy mix or specific components thereof. For example, the mix may be perceived to be successful or disastrous in achieving policy objectives (Oberlander and Weaver, 2015). As such, soft institutions including culture and societal views can contribute to this form of feedback. Cognitive feedbacks can involve mass publics, especially if the policy mix is widely perceived as providing benefits or imposing losses relative to the status quo (Jacobs and Weaver, 2015). Public opinion can be particularly significant in the context of sustainability transitions if policy mixes impose concentrated losses on the public. This could occur, for example, through highly visible effects such as wind farms altering landscapes and triggering local opposition (Wolsink, 2007). Another example may be the policy mix imposing highly visible financial costs, e.g. though surcharges on electricity bills for supporting renewable energy (Lauber and Jacobsson, 2016).

Constituency feedbacks relate to whether changes of the policy mix predominantly lead to the mobilization of supporters or opponents of the change (Oberlander and Weaver, 2015, p.43). For example, the financial support provided for renewable energy technologies in Germany through the FiT over time led to an increasingly powerful coalition of green groups, renewables manufacturing firms, local energy cooperatives and installers who benefited from the policy. The political mobilisation of this coalition protected the policy against powerful opponents such as the utilities (Jacobsson and Lauber, 2006). In general, sustainability transitions face significant political challenges, as they typically require a reform of sectors long dominated by incumbent firms, typically with close relationships with state actors (Kern and Howlett, 2009). Consequently, more radical policy and wider institutional reforms are often politically contested by dominant coalitions, commonly consisting of incumbents who often lobby against major policy changes or try to actively undermine them during implementation (Markard et al., 2015; Stenzel and Frenzel, 2008). However, there are instances where such incumbents are not homogenous in their beliefs and actions. Markard et al. (2015) show that in the Swiss energy

transition several of the incumbent energy firms were supportive of policy reforms, suggesting that if firms see transitions as opportunities rather than as threats they are more likely to be supportive. Even if incumbents mobilize opposition against reforms, if powerful countervailing coalitions organise the reforms can be protected (Hess, 2014; Lauber and Jacobsson, 2016).

Agenda feedbacks cover whether satisfaction with, or objection to, the policy mix leads to the consideration of incremental changes to existing policy mix elements or more dramatic reforms (Oberlander and Weaver, 2015). Therefore, this form of feedback influences the stability of policy mix elements. How readily replaceable a certain element of the policy mix (such as a specific instrument) is considered, will influence its prospects for maintenance, revision or termination (Jordan and Matt, 2014). For example, if there are no obvious alternatives, opposing groups will struggle to make the case for reform or redesign (Jordan and Matt, 2014). In a policy mix, if certain instruments are considered replaceable and ineffective, modification or replacement with a new type of instrument may occur more readily. Similarly, if alternative options for achieving broader objectives (such as mitigating climate change) are seen as more effective or efficient, then radical changes to the mix may occur, including severe reductions in ambition or funding, or even termination of the policy strategy and its supporting instruments. For example, if demand reduction is advocated as more cost effective for achieving carbon abatement than replacement of existing generation capacity with sustainable alternatives, then instruments supporting sustainable generation technologies may lose political support.

4.2.2. Fiscal feedback mechanisms

"Fiscal feedbacks capture whether a [policy mix] creates budgetary strains that are likely to raise concerns among powerful actors, notably Treasury or Finance Ministers" (Oberlander and Weaver, 2015: 43). In most political systems, the finance ministry is a powerful organisation with the ability to control resource flows. It can exert substantial influence on the policy process, potentially weakening the autonomy of groups otherwise dominating the policy subsystem (Oberlander and Weaver, 2015).

A rapidly growing demand on the general budget (for example, if the earmarked funding stream becomes insufficient due to unexpected cost trends) and/or an ongoing funding crisis, will likely lead to strong concerns among budget guardians (Oberlander and Weaver, 2015: 42). In addition, over time as exogenous conditions (e.g. macro-level socio, economic and political trends) change, the priorities of the finance ministry may shift, and/or the perceived costs of supporting the policy mix may change accordingly. This is a significant risk for sustainability transitions, which are long-term processes. Therefore, if the policy mix can generate tax revenues or produce benefits which align with other ambitions such as economic growth or industrial development, it is more likely to attract or maintain support of the finance ministry who may prioritise these considerations over sustainability.

4.2.3. Administrative feedback mechanisms

Administrative feedbacks relate to the public bodies in charge of policy design and implementation (Oberlander and Weaver, 2015: 42). Administrative feedback can lead to strengthening or weakening of internal morale, sense of mission, external reputation, external political support, and the ability to recruit qualified staff (Oberlander and Weaver, 2015). Positive feedback can occur when policy objectives are clear and achievable, allowing public bodies to avoid highly visible failures and maintain a reputation for competence (Oberlander and Weaver, 2015). Negative feedbacks can occur if highly visible failures are blamed on the administrative bodies, which potentially damages reputation, internal morale and external support.

Consequently, administrative feedback may contribute to resultant policy mix changes such as the expansion or reduction of resources and capacities to design and implement policy (Pierson, 1993; Béland, 2010). For example, thinly staffed public bodies might lack the capabilities to perform the ambitious task of policy learning, reflexivity and adjusting policies to changing conditions (Borras, 2011). This may require the outsourcing of tasks and may reduce the autonomy of the public body. Alternately, a department with high reputation may assimilate a low reputation department, thereby broadening its mandate and taking on new responsibilities. Conversely, a department with low capacities may receive increased support in order to design and implement policies more effectively, if political support for the policy mix objectives is strong.

4.3. Exogenous conditions

The interplay between policy effects and feedback mechanisms occurs through changes within the socio-technical system. However, few policy changes occur purely through endogenous feedback mechanisms (Oberlander and Weaver, 2015), but instead are often also influenced by exogenous changes beyond the socio-technical system (Oberlander and Weaver, 2015; Rosenow, 2013). In the transitions literature, exogenous conditions (e.g. macro-economic trends, demographic changes, catastrophic events) are conceptualised as the landscape, where landscape developments may be putting pressure on the regime (Geels, 2002). We build upon this notion, while also considering learning and innovation outside the boundaries of the socio-technical system as exogenous conditions. Such exogenous conditions can influence the co-evolution of policy mixes and socio-technical change in a number of ways:

First, exogenous conditions can influence the rate and direction of change in the socio-technical system. Economic trends and innovation from outside the system can influence investment and market development, while the entry of new actors from other geographical settings may cause a change in networks or the legitimacy of certain technologies. Exogenous conditions may also influence the incentives of actors to participate in political action. Policy mix elements that originally generated positive feedbacks, may find that under different circumstances such as sudden, unexpected changes in market conditions, start to generate negative feedbacks (Patashnik and Zelizer, 2009). For example, in Germany, international competition from the Chinese PV industry weakened domestic support coalitions when German PV manufacturers went bankrupt and domestic PV manufacturing jobs were lost (Lauber and Jacobsson, 2016). This undermined the case for supporting the roll-out of (Chinese manufactured) PV modules for actors interested in creating industrial benefits in Germany (Lauber and Jacobsson, 2016; Quitzow, 2015b).

Second, exogenous conditions may amplify or constrain the influence that feedback mechanisms have on policy change. Feedback mechanisms are more likely to contribute to policy change when coupled with focusing events that bring attention to policy problems (Jacobs and Weaver, 2015; May and Jochim, 2013). For instance, negative feedback mechanisms are rarely a sufficient cause for policy mix change, often requiring other conditions or events to push policy makers to seek alternatives (Oberlander and Weaver, 2015). For example, a difficult fiscal climate may bring or increase attention to the relative costs of supporting a policy mix, and strengthen the case for cutting resources. Learning and innovation outside the boundaries of the socio-technical system can also affect feedback mechanisms. For example, learning from policy experiments elsewhere may instigate consideration of modifications to the policy mix (Jacobs and Weaver, 2015). In some instances, policy mix elements may remain unchanged simply because there are no obvious or known alternatives towards addressing the problem. Therefore, learning from outside the system boundaries may allow proponents of change to suggest policy or technological alternatives, thereby contributing to agenda feedbacks.

Third, exogenous conditions can also directly influence the policy subsystem, by changing which actors are represented or have influence over the policymaking process. Electoral cycles, changes in government

or changes in responsibilities or mandates within government, can change which actors are active in the policy subsystem. This may alter the influence of certain feedback mechanisms on policy change, if proponents/opponents of the policy mix resonate more closely with the ambitions or ideologies of the new or changed government. Interest groups and coalitions may ultimately only be successful in influencing policy change when sympathetic politicians gain power (Oberlander and Weaver, 2015). Electoral cycles may also change government's preferences regarding the style of policymaking, with potential repercussions for the policy mix (Patashnik and Zelizer, 2009). However, reforms are more resistant to changes in government if there is a strong domestic lobby supporting the policy strategy and corresponding instrument mix. For example, in Germany the Conservative-Social Democrat coalition continued to support the existing instruments in place for supporting renewables after coming to power, even at a time when the subsidies were contested because of contributing to rises in electricity prices, because of the existence of a strong domestic lobby (Lauber and Jacobsson, 2016; Geels et al., 2016).

Finally, international governance (UN, EU) may place pressure on national policymakers to implement policy reforms. One example is the pressure of the World Bank for all countries to phase out fossil fuel subsidies by 2025 (Hafeneth, 2017). Another example concerns the threat of reputational losses through not living up to international expectations, such as in the case of Germany's pending failure to meet its 2020 target for reducing greenhouse gas emissions by 40% (Podewils, 2018).

Considering these factors, the timing of policy implementation relative to exogenous conditions will influence the effects of the policy mix on the socio-technical system and the feedback mechanisms that occur (Pierson, 2000; Oberlander and Weaver, 2015). Poor timing can imply that conflicting objectives in other policy areas mean the policy mix is politically contested from the outset, or that changing exogenous conditions may shift priorities and reduce support for policy mix objectives (Patashnik and Zelizer, 2009).

4.4. Dynamic interactions of policy effects and feedback mechanisms

Having explained the conceptual components of the framework individually, we now turn to explaining possible interaction dynamics and feedback loops. In our elaboration of how the processes described above can interact dynamically over time we focus on explaining key interactions, notwithstanding that many more are conceivable.

Policy effects on socio-technical change can lead to positive and negative feedback mechanisms, which may strengthen or weaken support for the policy mix. Positive feedbacks, which maintain or strengthens support, are likely to lead to steady resource flows in favour of transitions which makes successive positive feedbacks more likely (positive feedback loop). Conversely, negative feedbacks may limit the capacity of the policy mix to become stable, and can reduce support and resources for the transition. Over time, reduced resources may result in successive negative feedback occurring (negative feedback loop) leading to the policy mix being revised or terminated. Therefore, the co-evolution of policy mix change and socio-technical change over time can lead to virtuous or vicious cycles.[3]

In the following subsections, we describe some conditions under which both positive (virtuous) and negative (vicious) feedback loops may occur. For the sake of concision, we abbreviate the key processes as: resource [RE], interpretive [IntE] and institutional [InstE]; socio-political [SPF], fiscal [FF] and administrative [AF] feedbacks; and exogenous conditions [ExC].

[3] Such cycles can however be interrupted, for example through changing exogenous conditions.

4.4.1. Virtuous cycles of positive feedback loops

Positive feedback mechanisms are most commonly generated when a policy mix provides resources that are visible and traceable to government action [RE] (Arnold, 1990), incentivising supporting constituencies to protect these resources [SPF]. Similarly, if public resources are used to create beneficiaries in the wider public [RE] (Campbell, 2012), certain instruments may gain political support through formation of electoral coalitions or influencing mass cognitions in favour of support for the policy mix [SPF]. Reinforcing mechanisms may be most prominent where policy mixes encourage investment over long timeframes [RE], creating vested interests in supporting policy maintenance [SPF] (Arrow, 2000). This also generates positive expectations, signalling political commitment from government, and indicating stable investment conditions, thereby reducing investor risks [IntE].

Under these conditions, as the new configuration of the socio-technical system matures and niche actors gain market shares, these actors can form increasingly powerful coalitions and networks that challenge the ideas presented by regime actors who may become less influential in lobbying to retain the status quo [SPF]. Secondly, as supply chains are being established and upscaling of production occurs, this can lead to a growing market, improvements in technological performance and cost reductions. This strengthens the arguments put forward in support of the policy mix, which may change perceptions regarding costs of supporting the policy mix [SPF], which may also alleviate the concerns of finance ministers [FF] and improve the reputation of the policy makers responsible for designing the mix [AF]. This may enable expansion of state capacities in favour of the transition [InstE] and the maintenance or expansion of resources [RE]. As a transition matures, the wider diffusion of more sustainable technologies or practices can lead to widespread visible benefits, such as improved air quality, which has the potential to produce increasing levels of public support [SPF], which further sustains the policy mix and reinforces the new direction of travel of the socio-technical system.

4.4.2. Vicious cycles of negative feedback loops

If policy instruments are poorly designed, are overly complex, and/or are not well aligned with other instruments in the mix, they are expected to be limited in their transformative potential (Kivimaa and Kern, 2016) and their ability to generate positive feedbacks. A policy mix may be poorly designed if it does not provide sufficient resources [RE] or fails to sufficiently support niche technologies through protection and empowerment [RE & IntE & InstE]. Similarly, if resources are widely dispersed and 'hidden' from beneficiaries [RE & IntE], this renders the mix ineffective in mobilising support [SPF] (Patashnik and Zelizer, 2009). In such cases, the policy mix will not stimulate sufficient change within the socio-technical system to mobilise supporting constituencies or achieve its objectives [SPF], which can ultimately undermine political support.

Negative feedback mechanisms have been found to be most prevalent where layering of policy mix elements leads to complexity and inconsistency (Jacobs and Weaver, 2015), and elements seek to address multiple objectives, particularly when their success depends on the support of the general public (Skogstad, 2016). If the mix creates concentrated losses (or the expectation of concentrated losses) for powerful actors [RE], it will provide incentives for them to oppose the mix. However, if the policy mix fails to reform the institutional structures that support the existing regime [RE & InstE], or does not phase out support for unsustainable technologies or practises [RE], it is expected to facilitate regime actors in maintaining their influential position to oppose the mix through negative feedback [SPF]. Finally, if the amount of support (resources) reduces over time [RE], this can be interpreted as an indication of the direction of travel [IntE], and the level of political will towards meeting sustainability objectives (Rogge and Dütschke, 2017). This is most prominent if multiple conflicting changes occur (in rapid succession) leading to uncertainty and perceptions of

instability [IntE].

Under such conditions, the pace of transitions may be slow, as the policy mix does not enable green niche actors to grow and gain political influence in order to lobby for resources or to protect the sustainability objectives from opposition [SPF]. In such instances, it is expected that the existing and well-established networks between incumbents and policymakers ensure the stability of the regime through negative feedbacks [SPF]. Such negative feedbacks may lead to a reduction in political will supporting sustainability transitions and may result in reduced resources and revisions or terminations of policy mix elements. This could become even more likely if changes in exogenous conditions such as an economic recession or a shift in political ideologies [ExC] further undermine sustainability objectives.

5. An empirical illustration of policy mix feedbacks in sustainability transitions: the UK zero carbon homes policy mix

In this section, we briefly illustrate dynamics of the framework by drawing on the empirical example of the zero carbon homes (ZCH) policy mix in the UK. The ZCH target was announced in 2006 and entailed the ambition that by 2016 all new domestic homes in the UK should be zero carbon. This case provides a relevant illustration showcasing the utility of the proposed framework for several reasons. First, the ZCH target was intentionally designed as a policy mix with several policy instruments to meet the target. Second, the target was conceived to be very ambitious when introduced. Finally, the case provides a rich illustration of an instance where an ambitious policy mix failed to generate self-reinforcing positive feedbacks, leading to its abandonment in 2016.

5.1. Methodology

The illustration draws on an analysis of policy documents, industry journals, secondary literature, government consultations, select committee publications, inquiries, and debates in the House of

Commons and House of Lords over the period 2006–2016 (Table 1). Based on these, we established a chronology of events, mapping the elements of the policy mix and their changes over time (Fig. 3). We identified the relevant policy mix following the top down approach outlined by Ossenbrink et al. (this issue), considering the target and the instruments implemented towards achieving it.

Our illustrative case spans the period between September 2006 when the target was first announced, to May 2016 when the target was officially abandoned. For this period, we interpreted the changes in the policy mix through the different conceptual components of the analytical framework proposed in the previous section, which enables us to illustrate some of the interaction dynamics between policy effects and feedbacks in this case. We limit the illustration to the national policy level and focus on the co-evolution of the policy mix with the UK house building socio-technical system.

Table 1
Types of data source and quantity.

Type of data source	Quantity
Policy documents – Government response to consultations, publications (white papers), speeches, impact assessments	137
Zero carbon hub publications	148
Industry journals	603 – featuring most prominently ENDS report and Building magazine
Secondary literature	25 academic papers
Inquiries	71 written responses in Treasury inquiry 99 written responses in 'Home energy efficiency and demand reduction' inquiry, Energy and Climate Change Committee
Debates in the House of Commons and House of Lords over the period of 2006–2016	260 spoken references 22 written statements Most occurrences resulting from search terms 'Zero Carbon Homes' and 'Code for Sustainable Homes'
Letters (to government ministers)	3
Media	427 – Guardian, Telegraph, Financial Times, Independent

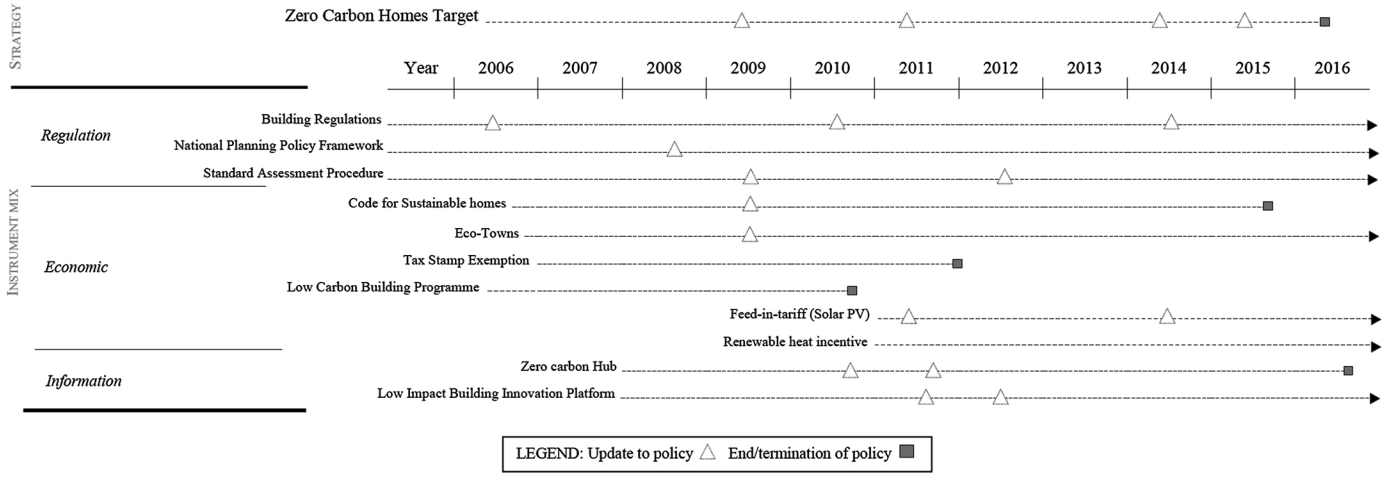

Fig. 3. Policy Mix for Zero Carbon Homes.

5.2. Overview of illustrative case

The zero carbon homes target sought to promote a radical paradigm shift in the UK house building socio-technical system by mainstreaming green building methods and techniques (Greenwood, 2012). It was adopted for a variety of reasons, including pressure from the EU as well as domestic considerations around meeting carbon targets, and formed a component of the UK Low Carbon Transition Plan (HM Government, 2009).

The target was designed to work primarily through two main instruments, a voluntary instrument known as the Code for Sustainable Homes (CSH),[4] and planned updates to the Building Regulations, which became progressively more stringent leading to zero carbon requirements in 2016. An exemption from stamp duty (economic instrument) was also announced in 2007 for all houses built to zero carbon standards before 2012.

After its announcement, the ZCH target underwent several significant redefinitions, as described in detail by Greenwood (2012, 2015), Heffernan et al. (2015) and Schweber et al. (2015). Also, despite being formalised in 2007, a definition of the technical specifications required to meet the target was not finalised until 2015. In parallel to the ZCH target, the government also aimed to build three million new homes by 2020 in order to tackle a housing crisis. At the time, this second policy target was seen to be complimentary with the ZCH target.[5]

5.3. Dynamics of policy effects and feedbacks: examples from the UK zero carbon homes policy mix

Throughout the evolution of the ZCH target, a number of policy effects and feedback mechanisms can help explain the revisions and eventual denouncement of the target. For our illustrative purposes, we use empirical examples to highlight some of the dynamics that played a role in these processes. First, we highlight a positive feedback loop occurring after the initial announcement leading to innovation and resource allocation and the expansion of capacities to design and implement policy. Secondly, we describe a series of negative feedback loops which led to the eventual denouncement of the target. In the following, we will use our analytical framework to highlight a number of important interactions and use the same abbreviations introduced above for the different processes stipulated in the framework: resource [RE], interpretive [IntE], and institutional [InstE] effects; positive (+) or negative (−) socio-political [SPF], fiscal [FF] and administrative [AF] feedbacks; and exogenous conditions [ExC].

5.3.1. Virtuous cycles: an empirical example

The target was first announced in 2006 and was accompanied by a voluntary standard for sustainable homes, planned updates to energy efficiency building regulations, and financial support through a tax exemption and public procurement. This created positive expectations of a potential market for low carbon housing technologies [IntE] and signalled political commitment to improving the efficiency of new buildings, leading to considerable growth of the green housing niche.[6]

In the mainstream building sector, there was little understanding of the methods required to significantly cut emissions among developers (ENDS Report, 2006), who were unwilling to move away from traditional methods (Osmani and O'Reilly, 2009; Gibbs and O'Neill, 2015). However, the expectation of potential resources being channelled into this area seems to have provided a strong enough market signal to stimulate innovative activity among incumbent actors [IntE]. Several of the major housebuilders were founding members of the UK Green Building Council (UK-GBC), a membership organisation which networks actors and provides information about sustainability in the built environment (Seager, 2007). Of these housebuilders, Barratt Homes was the first firm to prototype a demonstration of a zero carbon home,[7] and developed the first large scale housing scheme built to zero carbon standards.[8]

When announced, despite signalling political commitment from government, the original definition of the zero carbon homes target was a very general one, raising several questions which became the subject of significant debate across the building industry [IntE] (Greenwood, 2012). UK-GBC produced a report (2008) showing that the original 100% on-site energy generation requirement for ZCH was unachievable on 80% of sites in the UK. This suggested the original targets were overambitious, and brought attention to limited capabilities of government to design and implement effective policy [-AF]. However, due to the support from the building sector and political commitment from government towards the agenda [+SPF], positive agenda feedbacks resulted in incremental fixes to the strategy.

Acknowledging the concerns, the government commissioned the Callcutt review. Part of the recommendations made to government resulting from the review, was to establish a new platform to work towards an achievable target and implementation plan for the industry [+SPF]. In response, the Zero Carbon Hub was established [RE & InstE], a public private-partnership to act as a steering group towards achieving the target (Schweber et al., 2015). The target was redefined providing clearer guidance for industry on how to meet the target [IntE]. The Hub acted as a coordinator of various actors within the industry and produced research highlighting challenges and skill shortages the industry faced in the run up to 2016.

Overall, we argue these developments to be an example of a beginning virtuous cycle. A strong, long term policy target is established and accompanied by a range of instruments to meet the target. This leads to a positive response from the target group (the mainstream building sector) in terms of investments in pilot projects and knowledge development, and when questions about the definition of the target were raised, a public private partnership was set up to help industry to clarify and meet the target. However, as we will see in the next section these initially positive developments were soon overshadowed by other dynamics.

5.3.2. Vicious cycles: an empirical example

In 2010, the Labour government was succeeded by a Conservative-Liberal Democrat coalition, which introduced austerity policies in response to the financial crisis [ExC]. Related to the recession, there was also a shortage of supply of new housing in the UK which pushed up housing prices. This was highly visible in the general public and media [-SPF] and became a key priority for government. A deregulation agenda was pursued by the coalition Government as an attempt to increase the volume of new build in the UK, and the ZCH target was simply seen as another regulation impeding increased supply in this context [-SPF].

As reflected in the 2010 spending review, the perceived relative cost of supporting the zero carbon homes agenda had clearly increased in the treasury [-FF], ultimately leading to a reduction of resources [RE].

[4] The Code for Sustainable Homes (DCLG, 2008) is the most prominent voluntary sustainability label for housing in England (Heffernan et al., 2015). The code was developed by BRE, a private company formally known as the Building Research Establishment (Greenwood 2012), and managed under the direction of the Department of Communities and Local Government (DCLG). The Code is a holistic sustainability rating tool in which homes are rated against indicators in nine categories. Homes can be awarded a star rating between levels 1 and 6, with 6 being the most sustainable (Heffernan et al., 2015).

[5] The combined objectives were intended to deliver 1 million zero carbon homes between 2016 and 2020.

[6] For example, the EcoBuild exhibition has grown from under 1000 to almost 60,000 visitors and 1200 exhibitors in 5 years.

[7] The Barratt Green House, which was showcased among other similar projects in the BRE's Innovation Park.

[8] Barratt started development on a site of 186 houses at Hannam Hall in 2008. The efficiency standards of the site were amended in line with the redefinitions of zero carbon throughout its development. Construction finished in December 2015.

The grant funding of the Zero Carbon Hub was reduced in 2010, and subsequently cut altogether in 2011[9] [RE]. In the 2011 budget, the target was redefined for a second time, reducing the overall amount of carbon abatement required. Implementation of the 2013 increase of energy efficiency requirements in the building regulations was delayed by a year and then only reflected a 6% increase on the 2010 regulations.[10] Collectively these changes were largely considered by industry to be a weakening of government commitment towards the target [IntE], which seems to have slowed down socio-technical change. In the words of Jo Wheeler[11]: "The watering down of the definition of zero-carbon, coupled with the uncertainty surrounding standards for Part L [building regulations] 2013 and 2016 has inevitably resulted in a decline in innovation" (ENDS Report, 2013).

The decline in innovation in the sector due to an uncertain political climate made the achievement of the targets less and less likely in the run up to 2016. The delayed and reduced 2013 building regulation requirements subsequently meant a larger increase in energy efficiency was needed in a shorter period in order to meet the target. Opposing constituencies, consisting of some of the more conservative actors in the mainstream building sector, put forward the argument that the cost of meeting the target would further reduce the volume of new build [-SPF], which seems to have resonated with the ambitions of the treasury to increase the supply of houses. Shortly after the 2015 election, where Conservatives gained an absolute majority [ExC], the target was disbanded. The denouncement came directly from the treasury, who justified the decision by stating that costs of meeting the target were a tax on development.[12]

After the denouncement of the target, the UK-GBC organised over 246 senior leaders from industry actors and interest groups to write an open letter to the Chancellor [+SPF] (UK-GBC, 2015a). The letter warned that the abandonment of the ZCH target had "undermined industry confidence in Government" and will "curtail investment in British innovation and manufacturing" [IntE]. Importantly, of the 246 signatories on this letter (UK-GBC, 2015b), none of the 25 top volume housebuilders over 2007–2010 or the top 20 in 2016 (Building, 2016) appeared on this list. It also excluded major housebuilders who had been founding members of the UK-GBC, such as Barrat and Crest Nicolson. We suggest this indicates that the beliefs of these actors had changed over time [IntE] and they withdrew their support for the agenda, fragmenting the supporting coalition [-SPF]. Without the continued support of these politically influential actors, the opposing constituencies were successful in lobbying government to abandon the target [-SPF].

Overall, we argue these developments to be an example of a vicious cycle. A change in government, a change of government priorities, and a reduction of resources together led to a decline in innovative activity in the sector and a delay of key policy changes, as well as a fracturing of the coalition supporting the target, ultimately leaving the policy mix in a vulnerable position.

6. Conclusions

Understanding the role of policy processes in influencing the rate and direction of sustainability transitions remains a fundamental challenge in the existing literature. In particular, the processes influencing the development of policy mixes rather than single policy instruments, remain under conceptualised and underexplored. In this paper, we therefore proposed a novel conceptual framework for analysing the co-evolution of policy mixes and socio-technical systems. The core of the framework consists of policy effects influencing socio-technical change, and resulting feedback mechanisms influencing the subsequent development of the policy mix. We consider the framework to be applicable to a wide range of sustainability transitions, such as in energy, mobility or agriculture.

We illustrated the interaction dynamics conceptualised in the framework using the zero carbon homes policy mix in the UK. This example initially displayed characteristics of a virtuous cycle, which became disrupted (partly by exogenous factors), and turned into a vicious cycle, leading to the eventual abandonment of the policy target. The illustration demonstrated that the proposed framework enables new insights on the co-evolution of developments in the policy subsystem and the UK building socio-technical system, helping to explain which processes contributed to this failed attempt of promoting a low carbon transition.

The illustration also helps identify limitations of the proposed framework. Most notable is the current conceptualisation of fiscal feedback adopted from the policy feedback literature. In the illustration, the treasury's priorities shifted towards increasing the volume of new build and considered the sustainability transition to impede upon this ambition, leading to opposition to the target from the treasury. This suggests that finance ministries may oppose a transition if it is seen to be conflicting with other ambitions such as economic growth, irrespective of whether the costs of supporting the mix are borne directly by the finance ministry itself. Similarly, quicker than expected uptake of solar PV in Germany led to concerns about the costs of supporting the technology, resulting in a reduction of resources (Lauber and Jacobsson, 2016). The same process played out in the UK less than a year after a FiT was introduced (Smith et al., 2014). In these cases the costs of supporting renewable energy was borne by the electricity bill payer, rather than the finance ministry. Therefore, we suggest further work may need to extend the scope of fiscal feedback mechanisms to account for these processes.

Additionally, further conceptual and empirical studies should deepen insights linking policy mix characteristics (such as credibility, comprehensiveness, consistency and coherence) to the kinds of expected policy effects and feedback mechanisms, and how changes of characteristics over time (e.g. its credibility decreasing) influence these dynamics. Finally, more attention should be paid towards the vertical dimensions of policy mix design (Howlett et al., 2017), including implementation of national level policies at the local scale. This could help develop the framework further, in particular, how policy mix elements spanning multiple levels of government can be integrated to reduce conflicts. These considerations may help further conceptualise how policy effects interact with the socio-technical system, and the kinds of resultant feedback expected to occur.

We argue that the proposed framework may help generate important insights for policy makers seeking to support sustainability transitions. It directs attention towards designing policy mixes capable of generating positive feedback, thereby strengthening political support over time. Without generating political support, contestation and potential conflicts with other policy objectives can result in a weakening, dismantling or removal of policy mixes for sustainability transitions (or constituent elements thereof). Consequently, we suggest that maintaining political support through creating incentives for participation from supporting groups and constituencies, is fundamental to maintaining momentum in sustainability transition processes.

It is sometimes argued in the sustainability transitions literature that powerful regime actors need to support the newly emerging socio-technical system for the transition to 'break through' (Rotmans and Loorbach, 2010). Therefore as seen through the lens of our framework, the argument would be that policy mix design should not only create incentives for emerging niche actors but also for powerful actors to support the transition (Raven et al., 2016; Kemp and Rotmans, 2004; Markard et al., 2015). In doing so, positive feedbacks can be

[9] Funding was subsequently awarded from government for specific projects, while majority funding was provided by the National House Building Council (NHBC).

[10] This was less than the lowest scenario (an 8% increase) considered in consultations.

[11] Senior policy advisor at the UK Green Building Council (UK-GBC).

[12] In the inquiry of the treasury, the additional average cost of meeting the target incurred per dwelling was estimated as £3500. This equates to 1.6% of the average cost of a UK house in 2016, which was £216,750.

strengthened while simultaneously reducing negative feedback if powerful actors, who would otherwise oppose the transition, have reason to support it.

However, others have argued that policy mixes need to support creative destruction processes by putting incumbents under pressure (Kivimaa and Kern 2016). In this vein and seen through the lens of our framework, positive feedbacks can be strengthened if the policy mix phases out resources for the incumbent regime configuration, or breaks up the institutional structures through targeted instruments. While such reforms will likely face opposition from the regime, they may be necessary as the transition matures to weaken the influence of powerful actors who are unwilling to change and would otherwise seek to undermine it. However, the timing of these interventions is relative to the phase of the transition (Rotmans and Loorbach, 2010, 131). If the policy mix attempts to displace the regime before alternative socio-technical configurations have matured and established sufficiently strong coalitions in their favour, the regime may mount significant opposition leading to backlash, which can reverse the direction of travel (Rotmans and Loorbach, 2010).

Building on these ideas, we suggest that the timing (Patashnik and Zelizer, 2009) and sequencing (Meckling et al., 2017) of policies should be relative to the phase of the transition. In the formative phase the mix should focus on the promotion of positive feedbacks while aiming to reduce negative feedback until the new socio-technical configuration becomes stable enough to withstand resistance from the regime. Over time, the policy mix can begin phasing out support for the old configuration, while providing incentives for incumbents who are willing to innovate and adapt to the new sustainable configuration. Beyond the reallocation of resources, this also requires the reconfiguration of supporting institutional structures to break the lock-in of the incumbent regime. Failing to reform institutions will likely dampen the ability of the new socio-technical configuration to become stabilised, and will facilitate continued resistance from the regime. These considerations illustrate how policy mix design for sustainability transitions is fraught with political difficulties, but the proposed framework may help analysts and policymakers to 'think through' the political logic of different potential policy effect and feedback mechanism interactions, and can thereby help inform their strategies for policy formulation and implementation.

Acknowledgement

The research on which this paper is based was partly 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.

References

Alkemade, F., Hekkert, M.P., Negro, S.O., 2011. Transition policy and innovation policy: friends or foes? Environ. Innov. Soc. Transit. 1 (1), 125–129.
Arnold, A.D., 1990. The Logic of Congressional Action. Yale Univ. Press, New Haven, CT.
Arrow, K.J., 2000. 'Increasing returns: historiographic issues and path dependence'. Eur. J. Hist. Econ. Thought 7 (1), 171–180.
Avelino, F., Rotmans, J., 2009. Power in transition: an interdisciplinary framework to study power in relation to structural change. Eur. J. Soc. Theory 12 (4), 543–569.
Avelino, F., 2011. Power in Transition. Empowering Discourses on Sustainability Transitions. Erasmus University, Rotterdam.
Baker, L., Newell, P., Phillips, J., 2014. The political economy of energy transitions: the case of South Africa. New Polit. Econ. 19 (6), 791–818. http://dx.doi.org/10.1080/13563467.2013.849674.
Baranzini, A., van den Bergh, J.C.J.M., Carattini, S., Howarth, R.B., Padilla, E., Roca, J., 2017. Carbon pricing in climate policy: seven reasons, complementary instruments, and political economy considerations. WIREs Clim. Change 8, e462. http://dx.doi.org/10.1002/wcc.462.
Béland, D., 2010. Reconsidering policy feedback: how policies affect politics. Adm. Soc. 42 (5), 568–590.
Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res. Policy 37, 407–429.
Borrás, S., Edquist, C., 2013. The choice of innovation policy instruments. Technol. Forecasting Social Change 80, 1513–1522.
Borras, 2011. policy learning and organizational capacities in innovation policies. Sci. Pub. Policy 38, 725–734.
Building, 2016. Top 20 housebuilders 2016. Building article. http://www.building.co.uk/top-20-housebuilders-2016/5082787.
Cairney, P., Heikkila, T., 2014. Comparing theoretical approaches. chapter 10. In: Paul Sabatier, A., Christopher Weible, M. (Eds.), Theories of the Policy Process, third edition. Westview Press, Boulder ISBN: 9780813349268.
Campbell, A.L., 2012. Policy makes mass politics. Annu. Rev. Polit. Sci. 15 (1), 333–351.
David, M., 2017. Moving beyond the heuristic of creative destruction: targeting exnovation with policy mixes for energy transitions. Energy Res. Soc. Sci. 33 (January), 138–146. http://dx.doi.org/10.1016/j.erss.2017.09.023.
del Río González, P., 2006. The interaction between emissions trading and renewable electricity support schemes: an overview of the literature. Mitigat. Adapt. Strat. Glob. Change 12, 1363–1390.
del Río González, P., 2010. Analysing the interactions between renewable energy promotion and energy efficiency support schemes: the impact of different instruments and design elements. Energy Policy 38, 4978–4989.
DCLG, 2008. Definition of Zero Carbon Homes and Non-domestic Buildings – Consultation. H.M. Government, London.
ENDS report, 2006. On the Road to Zero- Carbon Developments. Analysis. The Ends Report. . http://www.endsreport.com/article/16427/on-the-road-to-zero-carbon-developments.
ENDSreport, 2013. Home Energy Efficiency Still in the Doldrums. The Ends Report. . http://www.endsreport.com/article/38131/home-energy-efficiency-still-in-the-doldrums.
Flanagan, K., Uyarra, E., Laranja, M., 2011. Reconceptualising the policy mix for innovation. Res. Policy 40 (5), 702–713.
Foxon, T.J., Pearson, P.J.G., 2008. Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime. J. Clean. Prod. 16, 148–161.
Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A., Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energy Policy 33 (16), 2123–2137.
Foxon, T.J., 2011. A coevolutionary framework for analysing a transition to a sustainable low carbon economy. Ecol. Econ. 70 (12), 2258–2267. http://dx.doi.org/10.1016/j.ecolecon.2011.07.014.
Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36 (3), 399–417.
Geels, Frank W., Schot, Johan, 2010. The dynamics of transitions: a socio-technical perspective. In: Grin, John, Rotmans, Jan, Schot, Johan (Eds.), Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change. Routledge, pp. 11–104 ISBN 9780415876759.
Geels, F.W., Kern, F., Fuchs, G., Hinderer, N., Kungl, G., Mylan, J., Wassermann, S., 2016. The enactment of socio-technical transition pathways: a reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014). Res. Policy 45 (4), 896–913.
Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31 (8–9), 1257–1274.
Geels, F.W., 2004. From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. Res. Policy 33 (6–7), 897–920.
Geels, F.W., 2005. Processes and patterns in transitions and system innovations: refining the co-evolutionary multi-level perspective. Technol. Forecasting Social Change 72 (6 SPEC. ISS), 681–696.
Geels, F.W., 2014. Regime resistance against low-carbon transitions: introducing politics and power into the multi-level perspective. Theory Cult. Soc. http://dx.doi.org/10.1177/0263276414531627. (May 2013), 0263276414531627.
Gibbs, D., O'Neill, K., 2015. Building a green economy? Sustainability transitions in the UK building sector. Geoforum 59, 133–141. http://dx.doi.org/10.1016/j.geoforum.2014.12.004.
Gould, S.J., Eldredge, N., 1977. Punctuated equilibria: the tempo and mode of evolution reconsidered. Paleobiology 3 (2), 115–151.
Greenwood, D., 2012. The challenge of policy coordination for sustainable sociotechnical transitions: the case of the zero-carbon homes agenda in England. Environ. Plann. C: Gov. Policy 30 (1), 162–179.
Greenwood, D., 2015. In search of Green political economy: steering markets, innovation, and the zero carbon homes agenda in England. Environ. Polit. 24 (3), 423–441.
Guerzoni, M., Raiteri, E., 2015. Demand-side vs. supply-side technology policies: hidden treatment and new empirical evidence on the policy mix. Res. Policy 44 (3), 726–747. http://dx.doi.org/10.1016/j.respol.2014.10.009.
HM Government, 2009. The UK Low Carbon Transition Plan. TSO, Norwich. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/228752/9780108508394. pdf.
Hafeneth, T., 2017. Reforming Fossil Fuel Subsides for a Cleaner Future. The World Bank. http://www.worldbank.org/en/news/feature/2017/11/21/reforming-fossil-fuel-subsidies-for-a-cleaner-future.
Heffernan, E., Pan, W., Liang, X., De Wilde, P., 2015. Zero Carbon Homes: Perceptions from the UK Construction Industry.
Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: a new approach for analysing technological change. Technol. Forecasting Social Change 74 (4), 413–432.
Hess, D.J., 2014. Sustainability transitions: a political coalition perspective. Res. Policy 43 (2), 278–283.
Hess, D.J., 2015. The politics of niche-regime conflicts: distributed solar energy in the United States. Environ. Innov. Soc. Transit. 1–9.

Hoppmann, J., Huenteler, J., Girod, B., 2014. Compulsive policy-making − The evolution of the German feed-in tariff system for solar photovoltaic power. Res. Policy 43 (8), 1422–1441.
Howlett, M., Rayner, J., 2007. Design principles for policy mixes: cohesion and coherence in new governance arrangements. Policy Soc. 26 (4), 1–18.
Howlett, M., Rayner, J., 2013. Patching vs packaging in policy formulation: complementary effects, goodness of fit, degrees of freedom, and feasibility in policy portfolio design. Polit. Gov. 1 (December), 170–182.
Howlett, M., Vince, J., Del Río, P., 2017. Policy integration and multi-level governance: dealing with the vertical dimension of policy mix designs. Polit. Gov. 5 (2), 69. http://dx.doi.org/10.17645/pag.v5i2.928.
Jacobs, A.M., Weaver, R.K., 2015. When policies undo themselves: self-undermining feedback as a source of policy change. Governance 28 (4), 441–457.
Jacobsson, S., Bergek, A., 2011. Innovation system analyses and sustainability transitions: contributions and suggestions for research. Environ. Innov. Soc. Transit. 1 (1), 41–57.
Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology. Energy Policy 34 (3), 256–276.
Johnstone, P., Stirling, A., Sovacool, B., 2017. Policy mixes for incumbency: exploring the destructive recreation of renewable energy, shale gas fracking, and nuclear power in the United Kingdom. Energy Res. Soc. Sci. 33 (August), 147–162. http://dx.doi.org/10.1016/j.erss.2017.09.005.
Jordan, A., Matt, E., 2014. Designing policies that intentionally stick: policy feedback in a changing climate. Policy Sci. 47 (3), 227–247.
Jordan, G., Halpin, D., Maloney, W., 2004. Defining interests: disambiguation and the need for new distinctions? Br. J. Polit. Int. Relat. 6 (2), 195–212.
Kemp, R., Pontoglio, S., 2011. The innovation effects of environmental policy instruments − a typical case of the blind men and the elephant? Ecol. Econ. 72, 28–36.
Kemp, R., Rotmans, J., 2004. Managing the transition to sustainable mobility. In: Elzen, B., Geels, F.W., Green, K. (Eds.), System Innovation and the Transition to Sustainability, Theory, Evidence and Policy. Edward Elgar, Cheltenham, pp. 137–167.
Kemp, R., 1997. Environmental Policy and Technical Change. Edward Elgar, Cheltenham, Brookfield.
Kern, F., Howlett, M., 2009. Implementing transition management as policy reforms: a case study of the Dutch energy sector. Policy Sci. 42 (4), 391–408.
Kern, F., Rogge, K.S., 2016. The pace of governed energy transitions: agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? Energy Res. Soc. Sci. 22, 13–17.
Kern, F., Rogge, K.S., 2017. Harnessing theories of the policy process for analysing the politics of sustainability transitions: a critical survey. Environ. Innov. Soc. Transit. 0–1. http://dx.doi.org/10.1016/j.eist.2017.11.001.
Kern, F., Kivimaa, P., Martiskainen, M., 2017a. Policy packaging or policy patching?: The development of complex energy efficiency policy mixes. Energy Res. Soc. Sci. 23, 11–25.
Kern, F., Kivimaa, P., Martiskainen, M., 2017b. Policy packaging or policy patching? The development of complex energy efficiency policy mixes. Energy Res. Soc. Sci. 23, 11–25.
Kern, F., 2011. Ideas, institutions, and interests: explaining policy divergence in fostering system innovations towards sustainability. Environ. Plann. C: Gov. Policy 29 (6), 1116–1134.
Kivimaa, P., Kern, F., 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. Res. Policy 45 (1), 205–217.
Lauber, V., Jacobsson, S., 2016. The politics and economics of constructing: contesting and restricting socio-political space for renewables −the case of the German Renewable Energy Act. Environ. Innov. Soc. Transit. 18, 147–163.
Lehmann, P., 2010. Using a Policy Mix to Combat Climate Change − An Economic Evaluation of Policies in the German Electricity Sector. Universität Halle- Wittenberg (PhD thesis).
Loorbach, D., 2010. Transition management for sustainable development: a prescriptive, complexity-based governance framework. Governance 23 (1), 161–183.
Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects. Res. Policy 41 (6), 955–967.
Markard, J., Suter, M., Ingold, K., 2014. Energy transition and policy change − Advocacy coalitions in Swiss energy policy. In: IST Conference. October. pp. 1–31.
Markard, J., Suter, M., Ingold, K., 2015. Socio-technical transitions and policy change − advocacy coalitions in Swiss energy policy. Environ. Innov. Soc. Transit. 18, 215–237.
May, P.J., Jochim, A.E., 2013. Policy Regime Perspectives: Policies, Politics, and Governing 41. pp. 426–452.
Meadowcroft, J., Langhelle, O., 2009. Caching the Carbon. The Politics and Policy of Carbon Capture and Storage. Edward Elgar, Cheltenham and Northampton.
Meadowcroft, J., 2009. What about the politics? Sustainable development, transition management, and long term energy transitions. Policy Sci. 42 (4), 323–340.
Meadowcroft, J., 2011. Engaging with the politics of sustainability transitions. Environ. Innov. Soc. Transit. 1 (1), 70–75.
Meckling, J., Sterner, T., Wagner, G., 2017. Policy sequencing toward decarbonization. Nat. Energy 2 (12), 918–922. http://dx.doi.org/10.1038/s41560-017-0025-8.
Mettler, S., Soss, J., 2004. The consequences of public policy for democratic citizen- ship: bridging policy studies and mass politics. Perspect. Polit. 2, 55–73.
Mettler, S., 2002. Bringing the state back in to civic engagement: policy feedback effects of the G.I. Bill for World War II veterans. Am. Polit. Sci. Rev. 96 (02), 351–365.
Mourik, R., Raven, R., 2006. A Practioner' S View on Strategic Niche Management Towards a Future Research Outline. (December) 37.
Nauwelaers, C., Boekholk, P., Mostert, B., Cunningham, P., Guy, K., Hofer, R., Rammer, C., 2009. Policy Mixes for R&D in Europe. European Commission −Directorate −General for Research, Maastricht.
Normann, H.E., 2015. The role of politics in sustainable transitions: the rise and decline of offshore wind in Norway. Environ. Innov. Soc. Transit. 15, 180–193.
Normann, H.E., 2017. Policy networks in energy transitions: the cases of carbon capture and storage and offshore wind in Norway. Technol. Forecasting Social Change.
Oberlander, J., Weaver, R.K., 2015. Unraveling from within? the affordable care act and self-Undermining policy feedbacks. Forum 13 (1), 37–62.
Osmani, M., O'Reilly, A., 2009. Feasibility of zero carbon homes in England by : A house builder's perspective. Build. Environ. 44 (9), 1917–1924.
Ossenbrink, J., Finnsson, S., Bening, C. R., Hoffmann, V. H. (Submitted to Research Policy). Delineating policy mixes −contrasting the top down and bottom up approach along the case of energy storage in California.
Patashnik, E., Zelizer, J., 2009. When policy does not remake politics: the limits of policy feedback. In: Annual Meeting of the American Political Science Association. Toronto, Canada. pp. 1–39.
Patashnik, E.M., Zelizer, J.E., 2013. The struggle to remake politics: liberal reform and the limits of policy feedback in the contemporary american state. Perspect. Polit. 11 (4), 1071–1087.
Pierson, P., 1993. Policy feedback and policy change. World Polit. 45 (4), 595–628.
Pierson, P., 2000. Increasing returns, path dependence, and the study of politics. Am. Polit. Sci. Rev. 94 (2), 251–267.
Pierson, P., 2004. Politics in Time: History, Institutions, and Social Analysis. Princeton University Press.
Pierson, P., 2007. The costs of marginalization qualitative methods in the study of american politics. Comparat. Polit. Stud. 40 (2), 146–169.
Podewils, C., 2018. Records with Renewables, but Once Again No Progress on CO2 Emissions −2017 Was a Year of Mixed Success for the Energy Transition. Agora-Energiewende. https://www.agora-energiewende.de/en/topics/-agothem-/Produkt/produkt/464/Gemischte+Energiewende-Bilanz+2017%3A+Rekorde+bei+Erneuerbaren+Energien%2C+aber+erneut+keinerlei+Fortschritte+beim+Klimaschutz/.
Quitzow, R., 2015a. Assessing policy strategies for the promotion of environmental technologies: a review of India's National Solar Mission. Res. Policy 44, 233–243.
Quitzow, R., 2015b. Dynamics of a policy-driven market: the co-evolution of technological innovation systems for solar photovoltaics in China and Germany. Environ. Innov. Soc. Trans. 17, 126–148.
Raven, R., Kern, F., Verhees, B., Smith, A., 2016. Niche construction and empowerment through socio-political work. A meta-analysis of six low-carbon technology cases. Environ. Innov. Soc. Transit. 18, 164–180. http://dx.doi.org/10.1016/j.eist.2015.02.002.
Reichardt, K., Rogge, K., 2016. How the policy mix impacts innovation: findings from company case studies on offshore wind in Germany. Environ. Innov. Soc. Transit. 18, 62–81. http://dx.doi.org/10.1016/j.eist.2015.08.001.
Reichardt, K., Negro, S.O., Rogge, K.S., Hekkert, M.P., 2016. Analyzing interdependencies between policy mixes and technological innovation systems: the case of offshore wind in Germany. Technol. Forecasting Social Change 106, 11–21.
Reichardt, K., Rogge, K.S., Negro, S.O., 2017. Unpacking policy processes for addressing systemic problems in technological innovation systems: the case of offshore wind in Germany. Renew. Sustain. Energy Rev. 80, 1217–1226.
Rogge, K.S., Dütschke, E., 2017. Exploring perceptions of the credibility of policy mixes: the case of German manufacturers of renewable power generation technologies. SPRU Working Paper Series (SWPS) 23, 1–53.
Rogge, K.S., Johnstone, P., 2017. Exploring the role of phase-out policies for low-carbon energy transitions: the case of the German Energiewende. Energy Res. Soc. Sci. 33 (February), 128–137. http://dx.doi.org/10.1016/j.erss.2017.10.004.
Rogge, K.S., Reichardt, K., 2016. Policy mixes for sustainability transitions: an extended concept and framework for analysis. Res. Policy 45 (8), 1620–1635.
Rogge, K., Schleich, J., 2018. Do Policy Mix Characteristics Matter for Low-Carbon Innovation? A Survey-Based Exploration for Renewable Power Generation Technologies in Germany. Accepted in Research Policy.
Rogge, K.S., Kern, F., Howlett, M., 2017. Conceptual and empirical advances in analysing policy mixes for energy transitions. Energy Res. Soc. Sci. 33 (October), 1–10. http://dx.doi.org/10.1016/j.erss.2017.09.025.
Rosenow, J., 2013. The politics of the german CO2-Building rehabilitation programme. Energy Effic. 6 (2), 219–238.
Rotmans, J., Loorbach, D., 2010. Towards a better understanding of transitions and their governance. A systemic and reflexive approach. Transitions to Sustainable Development. New Directions in the Study of Long Term Transformative Change. Routledge, pp. 105–198.
Sabatier, P.A., Weible, C.M., 2014. Theories of the Policy Process, third edition. Westview Press, Boulder ISBN: 978081334926829.
Schmidt, T.S., Sewerin, S., 2017. Technology as a driver of climate and energy politics. Nat. Energy 2 (6), 17084. http://dx.doi.org/10.1038/nenergy.2017.84.
Schneider, A., Ingram, H., 2009. What is next for policy design and social construction theory? Policy Stud. J. 37 (1), 103–119.
Schweber, L., Lees, T., Torriti, J., Schweber, L., Lees, T., 2015. Framing evidence: policy design for the zero-carbon home. Build. Res. Inf. 3218 (February), 37–41.
Scrase, I., Smith, A., 2009. The (non-)politics of managing low carbon socio-technical transitions. Environ. Polit. 18, 707–726.
Seager, A., 2007. Construction Sector Rises to Challenge of Building Eco-friendly Homes of the Future. The Guardian. https://www.theguardian.com/business/2007/feb/28/communities.society.
Shove, E., Walker, G., 2007. CAUTION! Transitions ahead: politics, practice, and sustainable transition management. Environ. Plann. A 39 (4), 763–770.
Skocpol, T., 1992. Protecting Soldiers and Mothers: The Political Origins of Social Policy in the United States. Belknap Press, Cambridge, MA.

Skogstad, G., 2016. Policy Feedback and Self-reinforcing and Self- Undermining Processes in EU Biofuels Policy. 1763 (March).
Smith, A., Raven, R., 2012. What is protective space? Reconsidering niches in transitions to sustainability. Res. Policy 41 (6), 1025–1036.
Smith, A., Kern, F., Raven, R., Verhees, B., 2014. Spaces for sustainable innovation: solar photovoltaic electricity in the UK. Technol. Forecasting Social Change 81, 115–130.
Sovacool, B.K., 2016. How long will it take? Conceptualizing the temporal dynamics of energy transitions. Energy Res. Soc. Sci. 13, 202–215. http://dx.doi.org/10.1016/j.erss.2015.12.020.
Stenzel, T., Frenzel, A., 2008. Regulating technological change — the strategic reactions of utility companies towards subsidy policies in the German, Spanish and UK electricity markets. Energy Policy 36 (7), 2645–2657.
Turnheim, B., Berkhout, F., Geels, F., Hof, A., McMeekin, A., Nykvist, B., van Vuuren, D., 2015. Evaluating sustainability transitions pathways: bridging analytical approaches to address governance challenges. Global Environ. Change 35, 239–253.
UK-GBC, 2015a. Over 200 Businesses Urge Chancellor to Reconsider Scrapping Zero Carbon. UK-GBC News. http://www.ukgbc.org/news/over-200-businesses-urge-chancellor-reconsider-scrapping-zero-carbon.
UK-GBC, 2015b. Open Letter to George Osborne on Zero Carbon Policy [open Letter]. Constructing Excellence. Retrieved from. http://constructingexcellence.org.uk/open-letter-to-george-osborne-on-zero-carbon-policy/.
Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830.
Weaver, K., 2010. Paths and forks or chutes and ladders?: negative feedbacks and policy regime change. J. Publ. Policy 30 (2), 137–162.
Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change: combining insights from innovation systems and multi-level perspective in a comprehensive failures framework. Res. Policy 41 (6), 1037–1047.
Weible, C.M., 2014. Introducing the scope and focus of policy process research and theory. Chapter 1. In: Sabatier, Paul A., Weible, Christopher M. (Eds.), Theories of the Policy Process, third edition. Westview Press, Boulder ISBN: 9780813349268.
White, W., Lunnan, A., Nybakk, E., Kulisic, B., 2013. The role of governments in renewable energy: the importance of policy consistency. Biomass Bioenergy 57, 97–105.
Wieczorek, A.J., Hekkert, M.P., 2012. Systemic instruments for systemic innovation problems: a framework for policy makers and innovation scholars. Sci. Publ. Policy 39 (1), 74–87. http://dx.doi.org/10.1093/scipol/scr008.
Wolsink, M., 2007. Wind power implementation: the nature of public attitudes: equity and fairness instead of backyard motives. Renew. Sustain. Energy Rev. 11 (6), 1188–1207.