Six policy intervention points for sustainability transitions: a conceptual framework and a systematic literature review

Article (Accepted Version)

Kanger, Laur, Sovacool, Benjamin K and Noorkõiv, Martin (2020) Six policy intervention points for sustainability transitions: a conceptual framework and a systematic literature review. *Research Policy*, 49 (7). a104072. ISSN 0048-7333

This version is available from Sussex Research Online: <http://sro.sussex.ac.uk/id/eprint/92372/>

This document is made available in accordance with publisher policies and may differ from the published version or from the version of record. If you wish to cite this item you are advised to consult the publisher's version. Please see the URL above for details on accessing the published version.

Copyright and reuse:

Sussex Research Online is a digital repository of the research output of the University.

Copyright and all moral rights to the version of the paper presented here belong to the individual author(s) and/or other copyright owners. To the extent reasonable and practicable, the material made available in SRO has been checked for eligibility before being made available.

Copies of full text items generally can be reproduced, displayed or performed and given to third parties in any format or medium for personal research or study, educational, or not-for-profit purposes without prior permission or charge, provided that the authors, title and full bibliographic details are credited, a hyperlink and/or URL is given for the original metadata page and the content is not changed in any way.

Six policy intervention points for sustainability transitions: A conceptual framework and a systematic literature review

Abstract

Recent literature has turned considerable attention to the role of policy mixes in shaping socio-technical systems towards sustainability. However, the identification of relevant policy intervention points has remained a relatively neglected topic. This is a potentially significant oversight given that such intervention points constitute a mid-step between means (particular policy instruments) and overall goals (change in the directionality of socio-technical systems). By complementing existing work on policy mixes with additional insights from transitions literature, this paper formulates a conceptual framework of six policy intervention points for transformative systems change. The coding scheme developed on the basis of this framework is used to review current literature on policy mixes in sustainability transitions. It is shown that the latter has so far primarily focused on niche-regime dynamics while largely neglecting the broader context of these interactions. We argue that adopting a wider perspective on intervention points can aid future work on policy mixes by enabling the identification of root causes and critical problems of ongoing transitions, and to spot gaps in existing policy activities. The case of the Estonian energy system is used to briefly illustrate these possibilities. Methodologically, we demonstrate the value of combining theory-based concept-formation with a systematic literature review, enabling not only a provision of a summary of existing literature but also highlighting systematic gaps in that literature.

Keywords

Sustainability transitions, policy mixes, policy intervention points, transition pathways

JEL classification codes

O31, O33, O38

1. Introduction

The mounting challenge of climate change has led to increasingly urgent calls for rapid and deep decarbonization (SDSN and IDDRI, 2014; Geels et al., 2017a; Rockström et al., 2017). As industrial societies are fundamentally underpinned by various socio-technical systems (e.g., mobility, energy, food), radical and coordinated changes in their basic mode of operation are called for (Schot and Kanger, 2018; Kanger and Schot, 2019). In particular, work in the sustainability transitions field (Grin et al., 2010; Markard et al., 2012; Köhler et al., 2019) has focused on identifying the preconditions, driving mechanisms, broad patterns and possibilities for accelerating radical transformations in socio-technical systems.

In parallel, there has been a growing recognition in the policy studies and innovation policy fields that sustainability transitions require new approaches. Over the past decade a third generation of innovation policy has been emerging (Steward, 2012; Diercks et al., 2018; Schot and Steinmueller, 2018). While the first generation (dominant in the post-WWII era) focused on the relationship between basic science and its applications, and the second (onward from the 1980s) on accelerating the speed of innovation, the third generation aims to tackle the directionality and goals (Stirling, 2008) of socio-technical systems. Correspondingly, the implementation of policy instruments from each generation can result in either market, structural system or transformational system failures (Weber and Rohrer, 2012). The notion of 'policy mixes' – a set of policy goals, strategies, instruments and policy processes that influence a given sector or system (and ideally support each other) – has experienced a similar shift. Originating from economic policy literature (Mundell,

1962), it was subsequently adopted by innovation system studies (Soete and Corpakis, 2003; Borrás and Edquist, 2013) and has been increasingly deployed in sustainability transitions literature (Kern and Howlett, 2009; Kivimaa and Kern, 2016). Put together, current literature stresses a need to design, evaluate, and implement appropriate policy mixes to shape the directionality of socio-technical systems while avoiding transformational system failures.

The literature on policy mixes in sustainability transitions has made steady progress in the identification and analysis of particular policy instruments (Kivimaa and Virkamäki, 2014), elements, policy processes and desirable characteristics of policy mixes (Rogge and Reichardt, 2016), and in the specification of feedback loops between policy processes and systems change (Edmondson et al., 2019). However, to date it has not systematically addressed the topic of policy intervention points, i.e., particular areas in the socio-technical system or its environment where the application of appropriate policy instruments would likely facilitate transformative change in the system's directionality. This is a potentially significant oversight given that the identification of key loci for policy intervention constitutes a mid-step between means (mixes of particular policy instruments) and overall goals (changes in the directionality of socio-technical systems). In other words, existing literature has largely focused on the 'what' and 'why' of policy mixes for systems change to the relative neglect of 'how'.

This paper aims to address that gap. It does so by using existing transitions theory to derive insights on various possible policy intervention points and by contrasting them to the current literature on policy mixes in sustainability transitions. More specifically, we pose the following research questions:

1. What does the literature on sustainability transitions reveal about policy intervention points for transformative systems change?
2. What does the literature on policy mixes reveal about policy intervention points for systems change?
3. What do insights from both literatures imply for the analysis and design of policy mixes for transformative systems change?

As such, we aim to make three contributions to existing literature. First, by complementing existing work on policy mixes with additional insights from transitions literature, we provide a conceptual framework comprising of six policy intervention points for sustainability transitions. In particular, we aim to show how transitions theory can be used to go beyond the dominant framing of intervention points as found in the current policy mixes literature. Second, we demonstrate the methodological value of combining a theory-guided approach with a systematic literature review, arguing that in contrast to literature-driven reviews, such an approach can reveal systematic gaps in state-of-the-art research that might be otherwise missed. Third, we show how the results of this mapping can improve further research on policy mixes in sustainability transitions by enabling the identification of the root causes hindering transformative change, critical problems worth special attention, and gaps in existing policy activities.

Although in our theory-building and literature review we have drawn on studies based on various theoretical frameworks, we ultimately chose to structure our own conceptualization of policy intervention points around the Multi-Level Perspective (MLP) on socio-technical transitions, in particular the 'global' model that captures an entire transition process (Geels, 2005a; Grin et al., 2010). As one of the earliest and most mature frameworks in the sustainability transitions field, MLP offers a sophisticated analytical vocabulary for theorizing the evolution of the focal socio-technical system as well as developments in its environment. It has developed a nuanced

understanding of how interactions on multiple levels – niche, regime, landscape – lead to different transition pathways (Geels and Schot, 2007). As such, we think MLP shows excellent promise in broadening the conceptual understanding of policy mixes for sustainability transitions, a promise we aim to illustrate below.

The paper is structured as follows. Section 2 presents a brief overview of the Multi-Level Perspective (Geels, 2005a), a selection of recent contributions to transitions literature that go beyond the dynamics of single socio-technical systems, and a summary of existing work on policy mixes for sustainability transitions. The purpose of this section is twofold: to identify a set of factors in the focal system and its environment facilitating transitions, and to reflect on the extent to which the issue of intervention points has been covered in current policy mixes literature. Section 3 describes the methodological approach of the paper – concept-formation coupled with a theory-guided literature review – as well as its limitations. Section 4 presents the concept-formation part of our work. Drawing on various factors facilitating systems change, as identified in Section 2, we make an additional analytical step by re-conceptualizing them as six policy intervention points for transformative change. Each point is illustrated with diverse empirical evidence, encompassing multiple niches and regimes in the domains of energy, mobility and urban planning. We also discuss the importance of these intervention points for various transition pathways. Section 5 presents the results of the literature review, demonstrating that the current discussion of policy mixes in sustainability transitions tends to be dominated by particular loci of intervention. Examples from the Estonian energy system are used to illustrate how the analysis of policy mixes can be improved by adopting a broader framework. Section 6 concludes, suggesting avenues for future research.

2. Background: Sustainability transitions and policy mixes

2.1 Factors shaping socio-technical transitions: The Multi-Level Perspective and beyond

Transitions can be defined as long-term (50 years and more) shifts from one socio-technical system to another (Geels and Schot, 2010: 11). A socio-technical system refers to a configuration of actors, rules and technologies for the fulfilment of a particular societal function, such as communication, food provision or transportation. This configuration encompasses the dimensions of science and engineering, economy, policy, everyday life, consumer behaviour and culture. For example, a system of personal land-based transportation entails the mutual alignment of vehicles, road infrastructure, repair shops, dealer networks, production facilities, traffic regulation, users' driving routines and symbolic meanings of the automobile (Geels, 2005a: 147).

The Multi-Level Perspective (MLP) is a prominent approach in transitions studies, synthesizing insights from evolutionary economics, structuration theory and institutionalism. It proposes that transitions come about through interrelated processes on three levels: niche, regime and landscape (Geels, 2002, 2005a). Socio-technical regimes are defined as shared, stable and aligned sets of rules directing the behaviour of actors in a particular system. These rules are embedded in various elements of the socio-technical system, and they shape innovative activities towards a specific trajectory of incremental innovation (e.g., increasing the fuel efficiency of cars). Radical alternatives to regimes are developed in spaces called niches. These are application areas dominated by specific selection criteria that shield the emerging new and unstable technologies from direct market pressure (e.g., military applications prioritizing performance over costs). Finally, the 'landscape' represents exogenous macro-level forces, such as wars or demographic changes, which shape niches and regimes but are not shaped by them (in the short and medium term).

Transitions usually begin when landscape changes put pressure on the dominant regime. As an initial response the regime attempts an internal fix to its problems. For example, 19th century urbanization exacerbated the low-speed problem of horse-drawn carriages, leading to the introduction of horse-drawn rail cars. The same pressures, however, also provided a 'window of opportunity' for niches such as bicycles (Geels, 2005b). As the regime becomes further destabilized, it prompts a need for a fundamental transformation of its basic architecture. This involves interactions between the regime and emerging niches and between the niches themselves, e.g., bicycles, trams and automobiles competing with horse-drawn carriages in urban passenger transport (*ibid.*). Depending on the situation, this process can be more or less competitive in nature. As the emerging system stabilizes along various dimensions, establishing new production, distribution and consumption routines, a regime shift is completed. This is reflected in a sharp increase in the adoption of the focal technology of the system, e.g., the growth in car density in Western European countries after World War II (Mom, 2014: 289).

The intensity of landscape pressure, the resilience of the focal regimes and the maturity of niches can be thought of as factors determining whether transitions occur. Further work has shown that the particular combinations of these factors lead to particular transition pathways (Geels and Schot, 2007, 2010). For example, if the dominant regime starts to crumble before niches have matured, a drawn-out competition between various niches follows (de-alignment and re-alignment pathway); if, however, niches are mature, the transition will likely follow the technological substitution pathway (see Table 1 for an overview).

[Insert Table 1 around here]

Recent advances in the geography of transitions have focused on the multiple locational advantages of regimes or their 'socio-spatial embeddedness' (Coenen et al., 2012), including informal localized institutions (Raven et al., 2012), natural resource endowments, physical infrastructure (Bridge et al., 2013) or regional industrial specialization (Hansen and Coenen, 2015). A societal embedding framework (Geels and Johnson, 2018; Mylan et al., 2018) has been used to analyse the ways in which radical innovations become embedded in user, business, cultural, regulatory and transnational environments (Kanger et al., 2019). A common feature of these works is their focus on links between a socio-technical system and its broader environment. These findings suggest that transformative change happens when regimes are dis-embedded from their environment, severing the ties between incumbent actors and their support network. However, industry destabilization is likely to be a disruptive and contested process (Turnheim and Geels, 2013; Kungl and Geels, 2017), involving societal impacts extending beyond the focal system itself. Therefore, the work on 'just transitions' (Swilling and Annecke, 2012; Swilling et al., 2016) has stressed the need to commit to the dual goal of sustainability and human welfare in enacting systems change.

The MLP has also been applied to study the evolutionary patterns of multiple regimes (Geels, 2007; Papachristos et al., 2013; Sutherland et al., 2015), involving competition, symbiosis, integration and spill-over (Raven and Verbong, 2009; Hiteva and Watson, 2019). It has been shown that systems link to each other through various couplings, such as shared infrastructures or input-output relationships (Konrad et al., 2008). The recent Deep Transitions framework (Schot and Kanger, 2018; Kanger and Schot, 2019) proposes that interactions between single socio-technical systems produce 'long waves' (Freeman and Louçã, 2001; Perez, 2002) that, in turn, accumulate into a set of broader continuities characterizing the industrialization process as a whole. In different ways, all these works underline a common theme: transitions in a focal system might often depend on changes taking place in other systems. This implies that attempts to steer transitions might often need to take into account multi-regime linkages and interactions.

Taken together, our review highlights a number of factors shaping transitions, operating at the niche level and the regime level, as well as the broader environment of niches and the focal regime. Earlier works on MLP, focusing on the patterns of single system transitions, argued that transitions happen when the focal regime is unable to solve its problems internally, when niches challenging the incumbent regime are available and sufficiently mature, and when landscape pressures simultaneously destabilize the regime and provide a window of opportunity for niches. More recent work has approached the environment of socio-technical systems in a more nuanced manner, highlighting the broader impacts of dis-embedding the focal system from its socio-spatial environment. It has also explored the role of linkages between multiple socio-technical systems in either facilitating or inhibiting transition in the focal system.

2.2 Policy mixes in sustainability transitions

The concept of 'policy mix' has been used and developed in many domains, mainly environmental economics, innovation studies, and policy sciences (Howlett and Rayner, 2007). Having grown out from a focus on finding the single 'best' policy instruments with the 'most optimal' policy results, later research shifted to the interaction and mutual support of different instruments aiming to identify their optimal combination (e.g., Smith, 1994; Gunningham et al., 1998; see Flanagan et al., 2011: 703-704, for the history of the term). Work in the sustainability transitions field started to advocate looking at an even broader picture: first, by expanding the focus from sector-specific studies to policy mixes crossing administrative sectors (Kivimaa and Virkamäki, 2014; Kivimaa and Kern, 2016) and second, by focusing on broader policy strategies in addition to specific instruments (Rogge and Reichardt, 2016).

This shift in focus is also reflected in the changing dimensions of policy evaluation. While the relevant qualities of single policy instruments include effectiveness, efficiency, equity and feasibility, the desirable characteristics of policy mixes include consistency, coherence, credibility and comprehensiveness (Rogge and Reichardt, 2016). Recently, Scordato et al. (2018) have added the concepts of timing and scale. This means increased attention on the sequence of policy instruments and other elements of the mix, as well as the need to combine policies operating at regional, national and international levels.

Existing work on policy mixes has been criticized for its over-reliance on single case or small-N research strategies, and insufficient attention being paid to terminology and variable definition. Arguably this has led to a lack of fruitful accumulation of empirical studies as well as insufficient theorization (Howlett and del Rio, 2015). As a response, recent work in transitions studies has attempted to improve the conceptual foundations of policy mixes, including their design and composition (Rogge et al., 2017; Edmondson et al., 2019), to quantify the temporal dynamics of policy mixes in large-N studies (Schmidt and Sewerin, 2019), and to employ mixed method strategies (Mavrot et al., 2019). Another stream of critique has noted a clear over-representation of European cases (Rogge et al., 2017) with the prominent exception of China (Ely et al., 2018; Chang et al., 2019).

In contrast, the topic of policy intervention points, which we define as particular areas in the socio-technical system or its environment where the application of appropriate policy instruments would likely facilitate transformative change in the system's directionality, has gained fairly little explicit attention in the policy mixes literature. It can be argued, however, that in many ways existing conceptual vocabulary already points in that direction. A good example is the notion of policy strategies, consisting of objectives and principal plans, as introduced by Rogge and Reichardt

(2016). Here one might argue that the existence of objectives, combined with principal plans of getting to these objectives, must inevitably describe a logic of intervening on some level. The main difference between the conceptualization of the policy strategy and our understanding of intervention points lies in their focus. While the policy strategy concept puts an emphasis on measurable targets and concrete plans, therefore including a wider array of different elements such as goals, roadmaps, guidelines, conventions, etc. (Rogge and Reichardt, 2016; Imbert et al., 2017), the notion of an intervention point clearly focuses on what to target in the first place and why targeting it would be a good idea. This way we explicitly position intervention points as a mid-step between overall goals (change in system directionality) and particular policy instruments for achieving these goals.

It has to be noted that, occasionally, existing literature on policy mixes comes very close to the notion of intervention points as used in our paper. For example, Kivimaa and Kern (2016) have assessed Finnish and British energy policy mixes according to whether they support 'motors of innovation' or 'motors of creative destruction'. Edmondson et al. have summarized state-of-the-art policy mix research in transitions studies, suggesting that its "two particular challenges concern destabilization and accumulation" (2019: 3). Nevertheless, it seems to us that, in general, the idea of intervention points, and especially its distinctiveness from the existing conceptual vocabulary, has not been clearly established in the policy mixes literature. As a result, we feel that the literature has yet to tackle the identification of intervention points in a systematic manner. In our view, this remains an important challenge because the design and implementation of successful policy mixes requires a clear understanding of the possible loci of transformative change in the first place. Therefore, in the following sections we seek to outline six policy interventions points, using the MLP framework to relate them to each other, and to demonstrate the implications of this exercise for current and future work on policy mixes for sustainability transitions.

3. Research design

Our approach begins by building from Taagepera's critique (2008, 2018) that social science generally tends to prioritize the empirically observable ('how things are?') to the relative neglect of the logically possible ('how things should be on logical grounds?'). This argument implies that, in addition to summarizing different empirical observations in a specific field (e.g., by conducting a systematic literature review), one should always be mindful of the possibilities implied by existing theoretical frameworks but not yet taken up in empirical research for one reason or another. In other words, whereas literature-driven approaches can provide a good descriptive overview of existing findings, they risk missing out on systematic gaps in the field. Translated into the context of our paper this means that if the work on policy mixes in sustainability transitions happens to be characterized by a specific framing, a review of only these studies, however systematically undertaken, does not suffice because it threatens to reproduce the already existing bias. This problem can be alleviated, however, if the review is coupled with analytical reasoning about the types of categories that can be logically observed in the first place.

For this reason, our research was conducted in two steps, concept-formation followed by theory-guided literature review. In the first stage, we focused on conceptualizing the logically possible based on our familiarity with MLP and more recent findings from transitions studies (as presented in Section 2.1). Although our creative interpretation of existing literature cannot be described in terms of a strict methodological procedure we can nevertheless highlight a number of analytical moves made in the process. These include a) reflecting on transitions in terms of a number of interacting factors shaping why and how transitions occur; b) identification of six such factors; c) translation of the six explanatory factors into prescriptive 'intervention points', highlighting where

different policy instruments should be applied in order to facilitate systems change; d) reflecting on the differing importance of these intervention points for particular transition pathways. The outcome of the concept-formation stage provided us with a conceptual framework; a set of logically possible policy intervention points structured around the 'global' model of MLP that could be mapped onto the policy mixes literature.

In the second stage, we conducted a theory-guided literature review, focusing on two questions: 1) to what extent are different policy intervention points present in the literature on policy mixes and sustainability transitions? 2) how systematically and clearly are different intervention points being addressed? For that purpose, we performed an article search in Science Direct and Scopus databases using the following keywords: (“sustainability transitions” OR “socio-technical transitions”) AND “policy mix”. This enabled us to locate studies that explicitly positioned themselves at the intersection of both transitions and policy mixes literature.

The abstract of each article was reviewed manually to decide whether or not the article would be included in the analysis. The main inclusion criterion was that the study had to make systematic use of both transitions theory and policy mixes (e.g., articles with only a casual reference to either field of study were excluded). Out of 154 initial items, 55 articles were eventually selected for further review. This included both empirical and conceptual papers published mostly between 2014-2019. Based on our framework we developed a simple coding scheme to record the following attributes for each article: presence of particular intervention points (from none to all six), systematic coverage (i.e., whether the particular intervention point was an integral part of the analysis or rather mentioned as an off-hand comment) and clarity of treatment (i.e., whether the policy mixes were clearly linked to particular intervention points or whether linking these two required a generous amount of interpretation from the reader). The coding was carried out by one of the authors and led to the identification of dominant themes as well as gaps in the existing literature. The coding scheme, results and excerpts from articles with brief explanations from the coder showing how the coding scheme was applied, can be found in Appendix A.

Three limitations of our research strategy should be noted. First, by focusing on two databases (Science Direct, Scopus) and journal articles with explicit positioning (policy mixes and sustainability transitions literature), studies concerned with the evaluation of transformative innovation policy but not necessarily framing the discussion in terms of both transitions and policy mixes (e.g., Bugge et al., 2018; Grillitsch et al., 2019) were excluded from our review. Second, as the coding was conducted by one of the authors, no inter-coder reliability check was performed. Third, following our decision to structure our conceptualization around MLP, the literature review in Section 2.1 was limited to insights on the overall dynamics of transitions, excluding many other themes in the literature (e.g., social innovation, power, niche-internal processes). Therefore, we recognize the possibility that our theory-guided approach might have directed our attention to particular intervention points to the possible neglect of others. Section 4 should therefore be treated as an attempt towards a more comprehensive framework of policy intervention points rather than a fixed all-encompassing final product.

4. Policy intervention points in sustainability transitions

In this section, we present the results of the concept-formation stage of our work: a framework of policy intervention points for transformative change. We begin by outlining the six policy intervention points, illustrating each with empirical examples from policy practice. We then discuss the salience of different intervention points for particular transition pathways.

4.1 Six policy intervention points for sustainability transitions

Section 2 identified a number of factors shaping why and how transitions occur, as well as giving a brief discussion of how these factors might be reflected in the current policy mixes literature. In line with multi-level thinking, we argued that these factors are present at the niche level and the regime level, as well as in the broader environment of niches and the focal regime (socio-spatial context, other regimes, landscape dynamics). The results of this section are based on our recognition that these factors can be further reinterpreted as prescriptions for facilitating transformative systems change. For example, if the literature outlines the inability of an existing regime to solve its problems internally as one of the key factors contributing to transitions, it would follow that transitions can be accelerated by purposeful attempts to destabilize the incumbent regime. Proceeding in such a manner for each factor identified in Section 2.1, we propose six policy intervention points for sustainability transitions: 1) stimulate different niches; 2) accelerate the niches; 3) destabilize the regime; 4) address the broader repercussions of regime destabilization; 5) provide coordination to multi-regime interaction; 6) tilt the landscape. Figure 1 provides a visual summary.

[Insert Figure 1 around here]

Figure 1. Six intervention points for systems change (based on Geels and Schot, 2007: 401).

4.1.1 Stimulate different niches

The MLP identifies itself as a cross-over between sociological approaches and evolutionary economics (Geels and Schot, 2007; Geels, 2010), encompassing not only social learning, collective interpretation and power struggles, but also the processes of variation, selection and retention. From the evolutionary perspective, variety in different niches plays an important role as it presents a pool of alternative solutions for challenging and transforming the incumbent regime (Schot and Geels, 2007). At the same time, emerging niches also need to become mature enough to enter the market: therefore, for a certain amount of time some regulatory shielding is often required.

Measures to stimulate niches include R&D funding schemes, public procurement, foresight exercises to create future visions, relaxing certain regulatory conditions, etc. (Kivimaa and Kern, 2016: 208-209). What is important for this intervention point is to sustain variety, e.g., supporting biofuels, electric vehicles (EVs), driverless vehicles and mobility-as-a-service as alternatives in the mobility system, or solar, wind, geothermal energy, community energy projects and decentralized production as alternatives in the energy system.

Chinese policy towards new energy vehicles (NEV) is a good example of this kind of stimulation by the government. In 2008, NEVs accounted for almost no share of the Chinese automotive market. Seven years later sales reached 330,000, turning China into the largest NEV market in the world. This impressive growth was made possible by government policies that did not pick winners at the niche level where very different competing solutions existed, including hybrids, fuel-cell vehicles and battery electric vehicles. Instead, government policies focused on financing the R&D of all the NEV technologies and intervening on the consumer side by offering purchase rebates to make all NEVs more accessible (Xu and Su, 2016).

4.1.2 Accelerate the niches

Emerging technologies need to cross the 'valley of death' between R&D activities and market entry (Schot and Geels, 2008). Furthermore, transitions are about systemic changes, including the combination of technological, organizational and institutional innovations, new user practices and

changing cultural meanings. This means that both the scale-up of single niches and the alignment of niches need to be supported to achieve systemic change. Measures to accelerate the niches include the creation of innovation platforms, the introduction of market-based policy instruments, the promotion of entrepreneurship, advice systems for small and medium enterprises, provision of venture capital, etc. (Kivimaa and Kern, 2016: 208-209). For example, in the energy system, state loans might be used to facilitate the commercialization and domestic take-up of solar energy. In the mobility system, niche alignment could be supported through regulatory intervention targeted at linking electric and driverless vehicles to a mobility-as-a-service business model.

Danish R&D investments in wind energy offer a paradigmatic example. From the 1970s, researchers started with low-tech windmill designs, took smaller steps in scaling up technologies, and engaged continually in product development. In this way, as the design of hubs, high-quality shafts, mechanical brakes, electronic control systems, components of the yaw-system, and quality gears were undertaken in a collaborative network, costs slowly declined. By 1985, Danish wind turbine manufacturers held 50% of the world market and had produced about 700 MW of the 1,500 MW of wind power installed in California. Before consolidation in 2001, four of the world's six largest wind turbine manufacturers were Danish. The Danes were able to achieve such status in an extremely cost-effective manner. Approximately \$2.4 billion was spent on wind energy related R&D worldwide between 1976 and 1995; the Danish government's R&D funding accounted for about 4.2% of this total, while the U.S. government's funding for wind turbine R&D was nearly 11 times greater (Sawin, 2001: 334-335). Although the Danish contextual conditions were generally favourable for government initiatives (Karnøe and Garud, 2012), the role of policymaking in the creation of broad-based 'innovative democracy' cannot be understated (Mendonça et al., 2009).

4.1.3 Destabilize the regime

Transitions do not happen merely when niches are present, even if they are mature and inter-linked to a certain degree. The incumbent regime also needs to become destabilized to allow niches to break through. Measures to destabilize regimes include taxes for putting economic pressure on the regimes, banning of specific technologies and practices, removing subsidies for certain industries, or balancing the involvement of incumbents in policy advisory councils with niche actors (Kivimaa and Kern, 2016: 208-209). For example, increased taxation of gasoline-based cars (combined with support for vehicles with alternative fuel sources) might be used to challenge the traditional mobility system. In the energy system, the state might cut subsidies for fossil fuel-based energy production or, as in the case of Norway's sovereign wealth fund, divest from companies exploring oil and gas (*The Guardian*, 08.03.2019).

Global efforts at subsidy reform represent active efforts to destabilize regimes. Sovacool (2017) has summarized evidence from 25 countries who implemented national subsidy reforms between 1952 and 2016. For example, several European states – Austria, Belgium, Czech Republic, Greece, Hungary, Italy, Poland, Portugal, and Slovakia – repealed reduced value added tax (VAT) rates to coal, fuel oil, natural gas, and electricity providers over the previous three decades. These artificially low VAT rates had been implemented to benefit poor households – similar to low VAT rates given on other 'basic needs' such as food. However, the VAT subsidies were eliminated when it was discovered that most of their benefits went to the rich, rather than the poor, since the wealthy tended to consume more energy. That removal had only a negligible impact on energy market prices but saved drastic amounts of tax revenue for the governments involved (IEEP et al., 2007). These efforts suggest that subsidy removal and reform can bring substantial positive impacts on energy prices or national economic development.

4.1.4 Address the broader repercussions of regime destabilization

Systems do not exist in isolation but are socio-spatially embedded in their surrounding environment on multiple scales (regional, societal, global) and in multiple ways, such as physical infrastructures, existing skills, and networks between actors, as well as shared cultural background (Coenen et al., 2012; Hansen and Coenen, 2015). This means that policy action should also be aimed at dis-embedding the system from its environment while anticipating and alleviating possible unintended consequences of this process. Measures to address the effects of regime destabilization include campaigns to combat the dominant cultural framings of the system, payments to industry for the closure of fossil fuel-based plants, provision of financial and educational support for managing structural unemployment and skill mismatch, or facilitating regional diversification of industrial activities (Spencer et al., 2018).

A strong example is the industrial restructuring of the Ruhr valley in Germany. Historically a coal-producing area, the region has been taking gradual steps towards becoming a green energy producer and a hub of renewable energy industry. The transition of the Ruhr area began with the “Coal Crisis of 1958”, when price regulation in Germany was ended and it became obvious that imported coal was much cheaper than German coal. This led to extensive subsidization by the federal government (Storchmann, 2005). At first it was mostly about helping the coal industry survive, but included some government action that ended up enabling a larger transition – the founding of new institutions of technical higher education and supporting the diversification of business in the region (Taylor, 2015).

From the 1980s, it became clearer that the situation needed a more thorough intervention. On one hand, technology parks and centres were founded to speed up new areas of business in the region (Taylor, 2015). On the other hand, more social protection programmes were created for coal miners, such as compensation mechanisms for lost earnings, money for vocational retraining and extra funding for early retirement in the case of closed mines (Storchmann, 2005). Since the 2000s, the economic restructuring of the region has been in full swing, and in 2007 the decision to close the last operational hard coal mine was made. Government has since focused on supporting local projects and initiatives, and programmes to generate more of them, while continuing social support for ex-miners (Taylor, 2015).

4.1.5 Provide coordination to multi-regime interaction

The trajectories of socio-technical systems are not only internally created; they also result from the mutually reinforcing developments in multiple systems (Geels, 2007; Konrad et al., 2008; Schot and Kanger, 2018). For example, the combination of suburbanized housing and individual privately-owned gasoline-based cars reinforces both the current housing system (cars enable easier access to more remote locations) as well as the mobility system (car ownership is practical in the context of urban sprawl, especially when public transport is not easily available). In order to break this feedback loop, urban sprawl and car-centred mobility need to be jointly tackled.

Evidence of this type of intervention can be found from urban transitions (Nevens et al., 2013; Schiller, 2016) as cities are essentially constituted by a configuration of multiple interlinked and overlapping systems. For example, since the 1970s the city of Freiburg in south Germany moved towards being an ecological city. For this purpose, various measures were employed, including support for renewables (hydropower, solar, biological fermentation) in the energy system, facilitation of multi-modality in the mobility system, and the implementation of measures to increase the energy efficiency of buildings in the housing system. Both urban planning and extensive public involvement have played an important role in this process (Zhao et al., 2017).

4.1.6 Tilt the landscape

Although MLP has often treated the landscape as an exogenous force that shapes niches and regimes but is not shaped by them, newer literature has started to address the landscape-making impacts of socio-technical systems (Schot and Kanger, 2018; Kanger and Schot, 2019). These works direct attention to the need to address broader factors extending beyond specific niches and regimes. It includes participation in international and global negotiations to arrive at collectively binding agreements that would create broader framework conditions for changing the directionality and dynamics of a broad range of socio-technical systems. Examples of these include the Paris Agreement to limit the global temperature increase to below two degrees Celsius, or the recent framework by the United Nations obliging countries to monitor and track the movement of plastics beyond their borders (*The Guardian*, 11.03.2019).

Probably the best-known example of this approach is the banning of chlorofluorocarbons (CFCs). CFCs refer to a group of stable halogen compounds widely used in variety of applications including refrigeration, solvents, blowing agents, and food freezing in the 1960s and 1970s. They migrate to the stratosphere where they photo-disassociate into chlorine and other compounds. The chlorine reacts with ozone, reducing the ability for ozone to act as a shield against ultraviolet radiation. The depletion of the ozone layer increases ultraviolet levels at the earth's surface and incidents of cancer, damage to crops and aquatic life, and changes in local climate (Shapiro and Warhit, 1983; Harper, 1994). When scientists determined that CFCs were damaging the Earth's ozone layer in the mid-1980s, the international community did not rely on caps, credits, and trading. Regulators responded with the Montreal Protocol in 1987, which originally aimed at cutting production of CFCs by 50% but was later amended to be a complete phase-out of CFCs for all industrialized countries by 1996 (Gorman and Solomon, 2002).

4.2 Policy intervention points and transition pathways

Having outlined the six policy intervention points for sustainability transitions, we now turn to the question of relating them to different transition pathways (see also recent attempts to connect policy mixes to transition pathways by Lindberg et al., 2019, and Rogge et al., 2020). Our overall argument is simple: since different transition pathways (see Table 1 for a summary) seem to be characterized by differing intensity – for example, a rather gradual change in the case of the reconfiguration pathway and a considerably more rapid change in the case of the substitution pathway – then, from the policy perspective, there seems to be a trade-off between promoting the speed of transitions and managing the resulting uncertainty of change. It also means that the process is likely to be highly contested by stakeholders with different and often conflicting interests. Therefore, although addressing all six intervention points remains crucial in each pathway, the relative importance of these intervention points likely depends on a particular pathway. Or, in other words, different pathways suggest different 'key intervention points' requiring special attention.

In the reproduction pathway, niches cannot break through because there is insufficient pressure on the regime. In transition accounts, such a pressure is often created by landscape events. Therefore, in order to break out from this pathway to substantive transformative change, tilting the landscape is often required. As argued above, this can often be achieved through the design and implementation of international policies. On a national level, shifts in the focal regime might also be indirectly promoted by pushing for changes in another system. For example, strong policy support for the adoption of EVs in the mobility system might create a stronger demand in the energy system to move away from fossil fuels.

It has been argued that the reconfiguration pathway characterizes large technical systems (e.g., electricity, telephone networks) because they cover large geographical areas and include a number of interrelated, often infrastructural technologies (Geels, 2005a: 265-266). Because of their size and scope, such systems are likely to be quite resilient to change. This, in turn, increases the possibility that system incumbents will attempt to either block broader change or adopt niche innovations for the purposes of regime optimization (incremental innovation), without altering the overall directionality of the system. In these conditions strong regime destabilization measures might be required to open up the regime and make it more susceptible to transformative change.

The transformation pathway is characterized by moderate landscape pressure and the presence of a regime clearly receptive to change while the niches remain immature (Geels, 2006b). In this pathway, therefore, measures for stimulating niche scale-up and alignment likely obtain particular significance.

In contrast, in the de-alignment and re-alignment pathway cracks in the regime appear far earlier and therefore the uncertainty regarding the combinations of niches constituting the future regime remains higher (Geels, 2005b). Therefore, critical challenges include both stimulating various niches and accelerating existing ones.

Finally, in the substitution pathway, transition is likely to proceed most rapidly, resulting in the highest degree of uncertainty. Wide-ranging structural change is likely to affect a majority of actors related to the incumbent regime. As technologies associated with the declining regime quickly become obsolete, incumbent firms might experience a rapid decline in market share leading, in turn, to a loss of employment (Burke et al., 2019). This might be made worse by the fact that industries are regionally concentrated and ill-adapted to shifts in their underlying knowledge base (Spencer et al., 2018). In these conditions, anticipation and alleviation of the societal impacts of transitions would become the most critical issue. Table 2 provides a summary of the foregoing discussion.

[Insert Table 2 around here]

5. Policy intervention points and policy mixes

Having outlined our conceptual framework, we now use it to assess state-of-the-art literature on policy mixes in sustainability transitions, highlighting the dominant themes and neglected dimensions. We then move on from a descriptive mapping of current literature to an empirical illustration of how our framework can be used to improve existing research on policy mixes.

5.1 Intervention points in policy mixes literature

Overall we performed a review of 55 articles, coding each for the presence of particular intervention points. If at least one intervention point was present, an article was further coded to assess the extent to which these intervention points were systematically addressed in the text, as well as the clarity with which each point was mentioned. While 4 articles out of 55 did not contain a reference to a specific policy intervention point, the remaining 51 articles mentioned different intervention points 130 times in total.

Table 3 presents the results of the review (excluding 4 articles that did not include any intervention points). The counts of each point have been split according to four possibilities arising from the combination of systematic coverage (systematic vs. non-systematic treatment of intervention points) and clarity (explicit vs. implicit treatment of intervention points). The rightmost column presents

the overall count for each of the four possibilities as well as their relative share. As can be seen from the table, different intervention points have been explicitly and systematically addressed in almost half of the instances (63 times, or 48%). The bottom row presents the total count of each intervention point as well as its share from the overall number of articles included in the review.

[Insert Table 3 around here]

Niche stimulation is the most commonly mentioned intervention point, occurring in almost every article (50 times or 98%). A typical example is the study by Lazarevic et al. (2020) on the Finnish construction industry that highlights the role of various government interventions (e.g., R&D programmes and municipality-funded projects) in stimulating rapid developments in wood-frame multi-storey construction. Another example is the case of energy storage technologies in California (Ossenbrink et al., 2019) where policymakers provided support to early-stage technology research, development and demonstration (e.g., the Energy Innovators Small Grant), which played an important part in enabling this niche.

Niche acceleration is another pervasive theme, occurring almost as frequently as niche stimulation (46 times, in 90% of the articles). For example, Figenbaum (2017) has described how the emergence of the Norwegian battery electric vehicle (BEV) market was influenced by government incentives for niche market actors. Throughout a 25-year period, different policies, including purchase incentives, were introduced to accelerate the BEV niche leading to the BEV market share of 17.1% in 2015. Another example comes from Germany where the government's policy of obligatory public procurement of kilowatt hours generated by wind as well as infrastructure investments enabled the growth of an offshore wind energy niche (Reichardt et al., 2016).

Existing literature has also turned considerable attention to the role of regime destabilization in sustainability transitions, a theme occurring 28 times (in 55% of the articles). Some examples include the phasing out of fluorescent light bulbs in the EU (Kivimaa and Kern, 2016), coal in the UK, the Netherlands and Quebec (Rogge and Johnstone, 2017), and unsustainable pulp and paper industries in Sweden (Scordato et al., 2018). An impressive example of regime destabilization is the German *Energiewende* that included a nuclear phase-out policy. The latter has been considered one of the most important factors in stimulating investments to renewable energy production, helping to bring about the German energy transition (Rogge et al., 2017).

Compared to the first three, other themes are virtually absent from the literature: broader repercussions of regime destabilization and landscape tilting both appear three times whereas multi-regime coordination is not mentioned at all. Existing literature highlights German coal phase-out as a good example of combining regime destabilization policies with the management of broader societal impacts, the latter including early pensions, retraining and investments in alternative industries in the region. Similar efforts for a just transition have been made in UK, Turkey, Iran, Namibia and the Philippines (Geels et al., 2017b). Imbert et al. (2017) describe an interesting case of landscape tilting through strategic multi-level action. The authors show how in the EU, both Germany and Italy have managed to push parts of their own national strategies on bioenergy to the EU level, thereby having EU level pressures, in turn, shape transitions in both countries.

Our overall results seem to confirm the assessment by Edmondson et al. (2019: 3): an overwhelming proportion of intervention points in current policy mixes literature (124 or 95.4%) is related to niche stimulation, niche acceleration and regime destabilization. This might be explained by two factors: first, developments in the policy mixes literature seem to reflect the overall field of transitions studies that has so far predominantly focused more on single systems and less on multi-

regime interaction and the landscape-making impacts of systems change. Second, because of the length of the review process, journal articles may inaccurately reflect the most recent advances in the field. For example, although addressing the broader repercussions of regime destabilization was largely a neglected theme in our literature review, a recent European Environment Agency report on the policy and practice of sustainability transitions explicitly acknowledges the importance of alleviating the negative consequences of systems change (EEA, 2019: 71). Nevertheless, the bottom line is that in comparison to the six logically possible intervention points, the current framing of the policy mixes literature seems to be more limited.

5.2 Applying the framework for policy assessment: the Estonian energy system

So far we have demonstrated the discrepancies between our conceptual framework and state-of-the-art literature on policy mixes in sustainability transitions. In this section we turn to demonstrating the implications of this discrepancy. We argue that the adoption of a broader view on policy intervention points, as presented in Section 4, can enhance existing research on policy mixes in three ways: 1) tracing the root cause hindering a transition; 2) identifying the possible transition pathway and the critical intervention point to be addressed; 3) mapping the policy mix allowing the identification of gaps in existing policy measures. In order to make our claims more tangible we use the case of the Estonian energy system to illustrate these possibilities. Rather than an exhaustive study, this is meant to serve as a brief 'proof of principle', an approach that has been used in several theoretical papers in the transitions and policy mixes literature (e.g., Fuenfschilling and Binz, 2018; de Haan and Rotmans, 2018; Edmondson et al., 2019).

As a member of the EU, Estonia is part of the collective effort to cut greenhouse gas emissions to 80% below 1990 levels by 2050 (European Commission, 2018). In 2016, however, the energy sector (including transport) accounted for almost 90% of total greenhouse gas emissions in Estonia (Estonian Ministry of Environment, 2018). Matters are made worse by the fact that the Estonian energy system is primarily based on oil shale that has a low Energy Return on Investment compared to other fossil fuels (Cleveland and O'Connor, 2011; Hall et al., 2014), substantially contributing to Estonia having one of the largest ecological per capita footprints in Europe (Global Footprint Network, 2017). In order to support the take-up of green technologies, the Estonian government has introduced subsidies for electric vehicles (2011-2014, reinstated in 2020), and renewables (hoping to phase out these subsidies within ten years) (ERR, 06.08.2019). At the same time, the state continues to subsidize the oil shale industry (the biggest energy company *Eesti Energia*, producing more than 90% of all electricity in Estonia, is state-owned) and to negotiate for exceptions for the industry at the EU level. As a result, Estonia currently ranks among the top three laggards in the EU concerning progress in fighting climate change (Climate Action Network, 2018).

If one was to analyse the Estonian energy system, focusing only on niche-regime dynamics, one would quickly conclude that the above description matches the main conclusions of Kivimaa and Kern (2016): as many other countries, Estonia tends to focus too much on niche support (e.g., renewable subsidies) in comparison to regime destabilization (reflected in continued state support for the oil shale industry). However, a closer analysis of the situation reveals that since the mid-1990s, proposals to transform the Estonian energy system have been repeatedly blocked by industry actors and policymakers on three grounds: concerns for energy security, regional unemployment and the potentially resulting political instability (Sillak and Kanger, 2020). In other words, the lack of regime destabilization has been directly caused by the socio-spatial embeddedness of the industry into its surrounding environment. In the Estonian case, therefore, our framework helps to identify the fear of societal repercussions as the root cause hindering energy transition and directs attention to the importance of policy measures for alleviating anxieties about the wider societal effects of the

phase-out of oil shale. In fact, Estonian environmental movements have attempted to pursue this very strategy, e.g., through campaigns stressing that the key to energy security lies in decentralized renewable-based energy production (Eesti Taastuvenergia Koda, 2014).

Another question concerns the potential transition pathway of the Estonian energy system. Given the gradually increasing landscape pressure of climate change affecting Estonia through its membership in international organizations, the increasing cost-effectiveness of renewables (REN21, 2019) affecting the country through global markets, and the relative fragility of the focal regime due to oil shale's inherent deficiencies as a source of energy (Cleveland and O'Connor, 2011; Hall et al., 2014), one could argue that the oil shale-based energy system is fairly unstable and is likely to be considerably affected by specific external shocks (e.g., changes in oil price, influencing the profitability of domestic energy production). Under these conditions it can be assumed that the Estonian energy transition would unfold through the substitution pathway involving a high speed of change and a high degree of uncertainty.

This would make the management of societal repercussions of regime destabilization doubly important as it is both a root cause hindering the transition and the critical intervention point given the likely future transition pathway. Therefore, our framework would direct attention to proactively managing the concerns of a large share of the population likely to be affected by these events. At the moment, however, the current government has taken the route of keeping the oil shale industry alive as long as possible. For example, the Estonian Minister of Finance has confirmed the state's willingness to temporarily compensate the miners while they are out of work (Põhjarannik, 11.06.2019). Furthermore, the state has recently approved a €125 million investment to open a new shale oil refining factory in 2024 (ERR, 27.03.2020).

Finally, our approach can also be used to highlight additional deficiencies of Estonian energy policy. First, in the context of oil shale-based energy production, policy support for EVs is unlikely to contribute to emissions reduction, indicating a failure to coordinate multi-regime interaction. Furthermore, during the last 15 years, Estonia has pursued a strategy of implementing ecological reforms to conform to EU regulations while simultaneously negotiating exceptions for the oil shale industry from that very union (Sillak and Kanger, 2020). This means that Estonian international policy has been rather opportunistic, trying to make use of landscape trends unfolding in two opposite directions.

To summarize: whereas the conventional literature on policy mixes would advise Estonian policy-makers to continue supporting various niches while turning more attention to regime destabilization, our framework would also direct attention to the importance of tilting the landscape, coordinating multi-regime interaction and managing the broader repercussions of regime destabilization, with the latter being a doubly critical intervention point. Each intervention point would require a joint application of mutually supporting measures. For example, regime destabilization could be facilitated through the design of a step-by-step policy strategy for phasing out oil shale, broader societal impacts could be alleviated through the buy-out of employees from the oil shale sector by providing a generous benefits package conditional on accepting retirement in a pre-specified time frame, use of renewable energy could be made mandatory for charging stations for EVs, and cross-party agreement could be reached for stopping the strategy of bargaining for an exception for the oil shale industry at the EU level.

6. Conclusions

This paper has distilled findings from the twin literatures of sustainability transitions and policy mixes into a conceptual framework of six policy intervention points, and related these points to various transition pathways. We showed that whereas the current literature on policy mixes is dominated by the agenda of niche stimulation, niche acceleration and regime destabilization, it has relatively neglected the management of broader repercussions of regime destabilization, coordination of multi-regime interaction and tilting the landscape. Using the example of Estonia's energy system, we demonstrated how the adoption of a broader framework would enable the advance of research on policy mixes by allowing the identification of root causes, critical problems and intervention points not sufficiently covered by existing instruments. This, in turn, could lead to the design of a more complete portfolio of policy instruments and strategies, facilitating a change in the directionality of socio-technical systems towards increased sustainability. The policy implications of our framework are twofold: first, the design of policy mixes should address all six intervention points; second, while all intervention points remain important for all pathways, their relative importance differs from one pathway to another.

Methodologically, our framework has demonstrated the value of combining thinking on the logically possible with mapping the empirically observable, enabling not only the provision of a summary of existing literature but also highlighting systematic gaps within it. Given the existence of a particular framing on intervention points in the policy mixes literature, it is unlikely we would have formulated such a framework had we started straight from the literature review. However, existing systematic reviews in the transitions studies field tend to be literature-driven (e.g., Fischer and Newig, 2016; Kivimaa et al., 2019; Savaget et al., 2019; Sengers et al., 2019). Based on our work, we advise remaining somewhat cautious about the extent to which such descriptive overviews manage to cover all analytical dimensions of substantive importance. As a broader theme, we would call for more theoretical reflection in the transitions field (Kanger, 2020) so that the summaries of empirical findings would also be coupled with analytical reasoning on what could have been observed but was not.

Because of space limitations, this paper has included only a brief empirical application of our ideas. Nonetheless, it points the way towards fruitful future research. Further work remains to be done in using the framework for a systematic mapping of gaps in policy mixes in different countries and systems. Given the recent interest in the issue of timing and sequence of policy mixes (Scordato et al., 2018), our framework also opens up the possibility of inquiring whether intervention points should be addressed in a different order depending on a specific transition pathway. Furthermore, the identification of gaps in policy mixes based on our framework can be complemented with an assessment of the range of possible actors involved in bringing about transformative change at particular intervention points (e.g., the role of firms, universities, national and local government and NGOs in the acceleration of a specific niche). Another step would be to assess the differing motivation and capabilities of these actors to effect such a change. This would enable the establishment of a more explicit connection between our framework and the issues of agency, power and politics, as discussed in recent transitions literature (e.g., Avelino and Wittmayer, 2016; de Haan and Rotmans, 2018; Sovacool and Brisbois, 2019; Geels, 2020). Such an analysis would help to direct attention to the conflictual and contested nature of transitions, involving multi-actor, multi-level and multi-regime interactions. Moreover, it is possible that a deeper engagement with these literatures would enable complementing our framework with additional intervention points.

Notwithstanding these future topics and directions, perhaps when policy intervention points are better acted upon, and insights across sustainability transitions and policy sciences better

harmonized, the future potential we map here will become better reflected in empirical data. This would ensure that research findings are translated into much needed action commensurate to the sustainable challenges facing society.

Acknowledgements

This work was supported by the Estonian Research Council grant PRG346 “Reshaping Estonian energy, mobility and telecommunications systems on the verge of the Second Deep Transition”. The authors thank Anna Bergek, Paula Kivimaa, session participants at the ICPP4 conference (2019) and three reviewers for their helpful comments and feedback.

References

- Avelino, F., and Wittmayer, J. M. 2016. Shifting Power Relations in Sustainability Transitions: A Multi-actor Perspective. *Journal of Environmental Policy & Planning* 18(5): 628-649.
- Bridge, G. Bouzarovski, S., Bradshaw, M., and Eyre, N. 2013. Geographies of energy transition: Space, place and the low-carbon economy. *Energy Policy* 53: 331-340.
- Borrás, S., and Edquist, C. 2013. The Choice of Innovation Policy Instruments. *Technological Forecasting & Social Change* 80(8): 1513-1522.
- Bugge, M. M., Fevolden, A. A., and Klitkou, A. 2018. Governance for system optimization and system change: The case of urban waste. *Research Policy* 48(4): 1076-1090.
- Burke, P. J., Best, R., and Jotzo, F. 2019. Closures of coal-fired power stations in Australia: local unemployment effects. *Australian Journal of Agricultural and Resource Economics* 63: 142-165.
- Cantner, U., Graf, H., Herrmann J., and Kalthaus, M. 2016. Inventor networks in renewable energies: The influence of the policy mix in Germany. *Research Policy*, 45(6): 1165-1184.
- Chang, R., Cao, Y., Lu, Y., and Shabunko, V. 2019. Should BIPV technologies be empowered by innovation policy mix to facilitate energy transitions? - Revealing stakeholders' different perspectives using Q methodology. *Energy Policy* 129: 307-318.
- Cleveland, C. J., and O'Connor, P. A. 2011. Energy Return on Investment (EROI) of Oil Shale. *Sustainability* 3: 2307-2322.
- Climate Action Network. 2018. *Off target: Ranking of EU countries' ambition and progress in fighting climate change*. Available online: <http://www.caneurope.org/docman/climate-energy-targets/3357-off-target-ranking-of-eu-countries-ambition-and-progress-in-fighting-climate-change/file>.
- Coenen, L., Benneworth, P., and Truffer, B. 2012. Towards a spatial perspective on sustainability transitions. *Research Policy* 41(6): 968-979.
- Costantini, V., Crespi, F., and Palma, A., 2017. Characterizing the policy mix and its impact on eco-innovation: a patent analysis of energy-efficient technologies. *Research Policy* 46(4): 799-819.
- De Haan, F. J., and Rotmans, J. 2018. A proposed theoretical framework for actors in transformative change. *Technological Forecasting & Social Change* 128: 275-286.
- Diercks, G., Larsen, H., and Steward, F. 2018. Transformative innovation policy: Addressing variety in an emerging policy paradigm. *Research Policy* 48(4): 880-894.
- Edmondson, D. L., Kern, F., and Rogge, K. S. 2019. The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions. *Research Policy* 48(10): 103555.
- Eesti Taastuvenergia Koda. 2014. *Taastuvenergia aastaraamat 2014*. Available online: <http://www.taastuvenergeetika.ee/wp-content/uploads/2016/12/Taastuvenergia-aastaraamat-2014-1.pdf>.
- ERR. 06.08.2019. Riik loodab kümne aastaga taastuvenergia toetused nullini viia. <https://www.err.ee/968165/riik-loodab-kumne-aastaga-taastuvenergia-toetused-nullini-viia>.
- ERR. 27.03.2020. Valitsus andis Eesti Energiale rohelise tule uue õlithase rajamiseks. <https://www.err.ee/1069628/valitsus-andis-eesti-energie-rohelise-tule-uue-olitehase-ehituseks>.
- Ely, A., Geall, S., and Dai., Y. 2018. Low Carbon China: Emerging Phenomena and Implications for Innovation Governance: Introduction to the Special Issue. *Environmental Innovation & Societal Transitions* 30: 1-5.
- Estonian Ministry of Environment. 2018. Greenhouse Gas Emissions in Estonia 1990-2016. National Inventory Report. Submission to the European Commission. Available online: https://www.envir.ee/sites/default/files/nir_est_1990-2016_15.03.18.pdf.
- European Commission. 2018. 2050 low-carbon economy. Available online: https://ec.europa.eu/clima/policies/strategies/2050_en.
- European Environment Agency. 2019. *Sustainability transitions: policy and practice*. Available online: <https://www.eea.europa.eu/publications/sustainability-transitions-policy-and-practice/sustainability-transitions-policy-and-practice/viewfile#pdfjs.action=download>.
- Figenbaum, E. 2017. Perspectives on Norway's supercharged electric vehicle policy. *Environmental Innovation & Societal Transitions* 25: 14-34.
- Fischer, L.-B., and Newig, J. 2016. Importance of Actors and Agency in Sustainability Transitions: A Systematic Exploration of the Literature. *Sustainability* 8(5), 21 pp. Doi:10.3390/su8050476.
- Flanagan, K., Uyarra, E., and Laranja, M. 2011. Reconceptualising the 'policy mix' for innovation. *Research Policy* 40(5): 702-713.
- Freeman, C., and Louçã, F. 2001. *As Time Goes By: From the Industrial Revolutions to the Information Revolution*. Oxford: Oxford University Press.
- Fuenfschilling, L., and Binz, C. 2018. Global socio-technical regimes. *Research Policy* 47(4): 735-749.
- Geels, F. W. 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy* 31(8-9): 1257-1274.

- Geels, F. W. 2005a. *Technological Transitions and System Innovations: A Co-Evolutionary and Socio-Technical Analysis*. Cheltenham, UK: Edward Elgar.
- Geels, F. W. 2005b. The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860-1930). *Technology Analysis & Strategic Management* 17(4): 445-476.
- Geels, F. W. 2006a. Major system change through stepwise reconfiguration: A multi-level analysis of the transformation of American factory production. *Technology in Society* 28: 445-476.
- Geels, F. W. 2006b. The hygienic transition from cesspools to sewer systems (1840-1930): the dynamics of regime transformation. *Research Policy* 35(7): 1069-1082.
- Geels, F. W. 2007. Analysing the breakthrough of rock'n'roll (1930-1970): Multi-regime interaction and reconfiguration in the multi-level perspective. *Technological Forecasting & Social Change* 74(8): 1411-1431.
- Geels, F. W. 2010. Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. *Research Policy* 39(4): 495-510.
- Geels, F. W. 2020. Micro-foundations of the multi-level perspective on socio-technical transitions: Developing a multi-dimensional model of agency through crossovers between social constructivism, evolutionary economics and neo-institutional theory. *Technological Forecasting & Social Change* 152: 119894.
- Geels, F. W., and Johnson, V. 2018. Towards a modular and temporal understanding of system diffusion: Adoption models and socio-technical theories applied to Austrian biomass district-heating (1979-2013). *Energy Research & Social Science* 38: 138-153.
- Geels, F. W., and Schot, J. 2007. Typology of sociotechnical transition pathways. *Research Policy* 36(3): 399-417.
- Geels, F. W., and Schot, J. 2010. The dynamics of socio-technical transitions: A socio-technical perspective. In J. Grin, J. Rotmans, J. Schot in collaboration with F. W. Geels, D. Loorbach, (eds.). *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*, New York: Routledge, pp. 11-101.
- Geels, F. W., Sovacool, B. K., Schwanen, T., and Sorrell, S. 2017a. Sociotechnical transitions for deep decarbonization. *Science* 357(6357): 1242-1244.
- Geels, F. W., Sovacool, B. K., Schwanen, T., and Sorrell, S. 2017b. The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule* 1(3): 463-479.
- Global Footprint Network. 2017. Ecological Wealth of Nations. Available at: http://www.footprintnetwork.org/content/documents/ecological_footprint_nations/ecological_per_capita.html.
- Gorman, H. S., and Solomon, B. D. 2002. The Origins and Practice of Emissions Trading. *The Journal of Policy History* 14(3): 293-320.
- Grillitsch, M., Hansen, T., Coenen, L., Miörner, J., and Moodysson, J. 2019. Innovation policy for system-wide transformation: The case of strategic innovation programmes (SIPs) in Sweden. *Research Policy* 48(4): 1048-1061.
- Grin, J., Rotmans, J., and Schot, J. 2010. *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*. New York: Routledge.
- Gunningham, N., Grabosky, P., and Sinclair, D. 1998. *Smart Regulation: Designing Environmental Policy*. Oxford: Oxford University Press.
- Hall, C. A. S., Lambert, J. G., and Balogh, S. B. 2014. EROI of different fuels and the implications for society. *Energy Policy* 64: 141-152.
- Hansen, T., and Coenen, L. 2015. The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. *Environmental Innovation & Societal Transitions* 17: 92-109.
- Harper, S. F. 1994. Tradable Permits: Practical Lessons from the U.S. Experience. *Climate Change: Policy Instruments and Their Implications*. Tsukuba, Japan: IPCC Working Workshop, pp. 132-144.
- Hiteva, R., and Watson, J. 2019. Governance of interactions between infrastructure sectors: The making of smart grids in the UK. *Environmental Innovation & Societal Transitions* 32: 140-152.
- Howlett, M., and del Rio, P. 2015. The parameters of policy portfolios: verticality and horizontality in design spaces and their consequences for policy mix formulation. *Environment and Planning C: Politics and Space* 33(5): 1233-1245.
- Howlett, M., and Rayner, J. 2007. Design Principles for Policy Mixes: Cohesion and Coherence in 'New Governance Arrangements'. *Policy and Society* 26(4): 1-18.
- Huang, P. 2019. The verticality of policy mixes for sustainability transitions: A case study of solar water heating in China. *Research Policy* 48(10): 103758.
- Imbert, E., Ladu, L., Morone, P., and Quitzow, R. 2017. Comparing policy strategies for a transition to a bioeconomy in Europe: The case of Italy and Germany. *Energy Research & Social Science* 33: 70-81.
- Institute for European Environmental Policy (IEEP), Ecologic, FEEM, and IVM. 2007. *Reforming Environmentally Harmful Subsidies*. Available online: http://ec.europa.eu/environment/enveco/others/pdf/ehs_sum_report.pdf.
- Kanger, L. 2020. Neglected systems and theorizing: A comment on the transitions research agenda. *Environmental Innovation & Societal Transitions* 34: 352-354.
- Kanger, L., and Schot, J. 2019. Deep Transitions: Theorizing the long-term patterns of socio-technical change. *Environmental Innovation & Societal Transitions* 32: 7-21.

- Kanger, L., Geels, F. W., Sovacool, B. K., and Schot, J. 2019. Technological diffusion as a process of societal embedding: Lessons from historical automobile transitions for future electric mobility. *Transportation Research Part D: Transport and Environment* 71: 47-66.
- Karnøe, P., and Garud, R. 2012. Path Creation: Co-creation of Heterogeneous Resources in the Emergence of the Danish Wind Turbine Cluster. *European Planning Studies* 20(5): 733-752.
- Kern, G., and Howlett, M. 2009. Implementing transition management as policy reforms: a case study of the Dutch energy sector. *Policy Sciences* 42: 391-408.
- Kivimaa, P., Boon, W., Hyysalo, S., and Klerkx, L. 2019. Towards a typology of intermediaries in sustainability transitions: A systematic review and a research agenda. *Research Policy* 48(4): 1062-1075.
- Kivimaa, P., and Kern, F. 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy* 45(1): 205-217.
- Kivimaa, P., and Virkamäki, V. 2014. Policy Mixes, Policy Interplay and Low Carbon Transitions: The Case of Passenger Transport in Finland. *Environmental Policy and Governance* 24(1): 28-41.
- Köhler, J., Geels, F. W., Kern, F., Markard, J., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., Nykvist, B., Onsongo, E., Pel, B., Raven, R., Rohrer, H., Sanden, B., Schot, J., Sovacool, B., Turnheim, B., Welch, D., and Wells, P. 2019. An agenda for sustainability transitions research: state of the art and future directions. *Environmental Innovation & Societal Transitions* 31: 1-32.
- Konrad, K., Truffer, B., and Voß, J.-P. 2008. Multi-regime dynamics in the analysis of sectoral transformation potential: evidence from German utility sectors. *Journal of Cleaner Production* 16(11): 1190-1202.
- Kungl, G., and Geels, F. W. 2017. Sequence and alignment of external pressures in industry destabilisation: Understanding the downfall of incumbent utilities in the German energy transition (1998-2015). *Environmental Innovation & Societal Transitions* 26: 78-100.
- Lazarevic, D., Kautto, P., and Antikainen, R. 2019. Finland's wood-frame multi-storey construction innovation system: Analysing motors of creative destruction. *Forest Policy and Economics* 110: 101861.
- Lindberg, M. B., Markard, J., and Andersen, A. D. 2019. Policies, actors and sustainability transition pathways: A study of the EU's energy policy mix. *Research Policy* 48(10): 103668.
- Markard, J., Raven, R., and Truffer, B. 2012. Sustainability transitions: An emerging field and its prospects. *Research Policy* 41(6): 955-967.
- Mavrot, C., Hadorn, S., and Sager, F. 2019. Mapping the mix: Linking instruments, settings and target groups in the study of policy mixes. *Research Policy* 48(10): 103614.
- Mendonça, M., Lacey, S., and Hvelplund, F. 2009. Stability, participation and transparency in renewable energy policy: Lessons from Denmark and the United States. *Policy and Society* 27(4): 379-398.
- Mom, G. P. A. 2014. *The Evolution of Automotive Technology: A Handbook*. Warrendale, PA: SAE International.
- Mundell, R. 1962. The appropriate use of monetary and fiscal policy for internal and external stability. IMF Staff Papers, March 1962, pp. 70-77.
- Mylan, J., Morris, C., Beech, E., and Geels, F. W. 2018. Rage against the regime: Niche-regime interactions in the societal embedding of plant-based milk. *Environmental Innovation & Societal Transitions* 31: 233-247.
- Nevens, F., Frantzeskaki, N., Gorissen, L., and Loorbach, D. 2013. Urban Transition Labs: co-creating transformative action for sustainable cities. *Journal of Cleaner Production* 50(1): 111-122.
- Ossenbrink, J., Finnsson, S., Bening, C. R., and Hoffmann, V. H. 2019. Delineating policy mixes: Contrasting top-down and bottom-up approaches to the case of energy-storage policy in California. *Research Policy* 48(10): 103582.
- Papachristos, G., Sofianos, A., and Adamides, E. 2013. System interactions in socio-technical transitions: Extending the multi-level perspective. *Environmental Innovation & Societal Transitions* 7: 53-69.
- Perez, C. 2002. *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Cheltenham, UK: Edward Elgar.
- Põhjarannik. 11.06.2019. Martin Helme: nutame või naerame, aga kaevuritele tuleb praegu peale maksta. <https://pohjarannik.postimees.ee/6704409/martin-helme-nutame-voi-naerame-aga-kaevuritele-tuleb-praegu-peale-maksta>.
- Raven, R., Schot, J., and Berkhout, F. 2012. Space and scale in socio-technical transitions. *Environmental Innovation & Societal Transitions* 4: 63-78.
- Raven, R. P. J. M., and Verbong, G. P. J. 2009. Boundary crossing innovations: Case studies from the energy domain. *Technology in Society* 31(1): 85-93.
- Reichardt, K., and Rogge, K. 2016. How the policy mix impacts innovation: Findings from company case studies on offshore wind in Germany. *Environmental Innovation & Societal Transitions* 18: 62-81.
- Reichardt, K., Negro, S. O., Rogge, K. S., and Hekkert, M. P. 2016. Analyzing interdependencies between policy mixes and technological innovation systems: The case of offshore wind in Germany. *Technological Forecasting & Social Change* 106: 11-21.
- REN21. 2019. *Renewables 2019: Global Status Report*. Available online: https://www.ren21.net/wp-content/uploads/2019/05/gsr_2019_full_report_en.pdf.

- Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., Schellnhuber, H. J. 2017. A roadmap for rapid decarbonisation. *Science* 355(6331): 1269-1271.
- Rogge, K. S., and Johnstone, P. 2017. Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende. *Energy Research & Social Science* 33: 128-137.
- Rogge, K. S., Kern, F., and Howlett, M. 2017. Conceptual and empirical advances in analysing policy mixes for energy transitions. *Energy Research & Social Science* 33: 1-10.
- Rogge, K. S., Pfluger, B., and Geels, F. W. 2020. Transformative policy mixes in socio-technical scenarios: The case of low-carbon transition of the German electricity system (2010-2050). *Technological Forecasting & Social Change* 151: 119259.
- Rogge, K. S., and Reichardt, K. 2016. Policy mixes for sustainability transitions: An extended concept and framework analysis. *Research Policy* 45(8): 1620-1635.
- Savaget, P., Geissdoerfer, M., Kharrazi, A., and Evans, S. 2019. The theoretical foundations of sociotechnical systems change for sustainability: A systematic literature review. *Journal of Cleaner Production* 206: 878-892.
- Sawin, J. 2001. *The Role of Government in the Development and Diffusion of Renewable Energy Technologies: Wind Power in the United States, California, Denmark, and Germany, 1970-2000*. Boston, MA: Tufts University, PhD dissertation.
- Schiller, F. 2016. Urban transitions: scaling complex cities to human size. *Journal of Cleaner Production* 112(5): 4273-4282.
- Schmidt, T. S., and Sewerin, S. 2019. Measuring the temporal dynamics of policy mixes – An empirical analysis of renewable energy policy mixes' balance and design features in nine countries. *Research Policy* 48(10): 103557.
- Schot, J., and Geels, F. W. 2007. Niches in evolutionary theories of technical change: A critical survey of the literature. *Journal of Evolutionary Economics* 17: 605-622.
- Schot, J., and Geels, F. W. 2008. Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management* 20(5): 537-554.
- Schot, J., and Kanger, L. 2018. Deep Transitions: Emergence, Acceleration, Stabilization and Directionality. *Research Policy* 47(6): 1045-1059.
- Schot, J., and Steinmueller, W. E. 2018. Three frames of innovation policy: R&D, systems of innovation and transformative change. *Research Policy* 47(9): 1554-1567.
- Scordato, L., Klitkou, A., Tartiu, V. E., and Coenen, L. 2018. Policy mixes for the sustainability transition of the pulp and paper industry in Sweden. *Journal of Cleaner Production* 183: 1216-1227.
- Sengers, F., Wieczorek, A. J., and Raven, R. 2019. Experimenting for sustainability transitions: A systematic literature review. *Technological Forecasting & Social Change* 145: 153-164.
- Shapiro, M., and Warhit, E. 1983. Marketable Permits: The Case of Chlorofluorocarbons. *Natural Resources Journal* 23: 577-591.
- Sillak, S., and Kanger, L. 2020. Global pressures vs. local embeddedness: the de- and restabilization of the Estonian oil shale industry in response to climate change (1995-2016). *Environmental Innovation & Societal Transitions* 34: 96-115.
- Smith, K., 1994. New directions in research and technology policy: identifying the key issues. STEP Report R-01, STEP Group, Oslo, ISSN 0804-8185.
- Sovacool, B. K. 2017. Reviewing, Reforming, and Rethinking Global Energy Subsidies: Towards a Political Economy Research Agenda. *Ecological Economics* 135: 150-163.
- Sovacool, B. K., and Brisbois, M. C. 2017. Elite power in low-carbon transitions: A critical and interdisciplinary review. *Energy Research & Social Science* 57, 101242: 1-10.
- Spencer, T., Colombier, M., Sartor, O., Garg, A., Tiwari, V., Burton, J., Caetano, T., Green, F., Teng, F., and Wiseman, J. 2018. The 1.5°C target and coal sector transition: at the limits of societal feasibility. *Climate Policy* 18(3): 335-351.
- Stirling, A. 2008. "Opening up" and "closing down" power, participation, and pluralism in the social appraisal technology. *Science, Technology, and Human Values* 33(2): 262-294.
- Steward, F. 2012. Transformative innovation policy to meet the challenge of climate change: sociotechnical networks aligned with consumption and end-use as new transition arenas for a low-carbon society or green economy. *Technology Analysis & Strategic Management* 24(4): 331-343.
- Soete, L., and Corpakis, D. 2003. R&D for competitiveness and employment - the role of benchmarking. IPTS report February 2003. Available online: <http://www.jrc.es/home/report/english/articles/vol71/welcome.htm>.
- Storchmann, K. 2005. The rise and fall of German hard coal subsidies. *Energy Policy* 33(11): 1469-1492.
- Sustainable Development Solutions Network (SDSN), and Institute for Sustainable Development and International Relations (ISDIR) 2014. *Pathways to Deep Decarbonization*. Available online: http://unsdsn.org/wp-content/uploads/2014/09/DDPP_Digit.pdf.
- Sutherland, L.-A., Peter, S., and Zagata, L. 2015. Conceptualising multi-regime interactions: The role of the agriculture sector in renewable energy transitions. *Research Policy* 44(8): 1543-1554.
- Swilling, M., and Anneck, E. 2012. *Just Transitions. Explorations of Sustainability in an Unfair World*. Claremont: UCT Press.

- Swilling, M., Musango, J., and Wakeford, J. 2016. Developmental States and Sustainability Transitions: Prospects of a Just Transition in South Africa. *Journal of Environmental Policy & Planning* 18(5): 650-672.
- Taagepera, R. 2008. *Making Social Sciences More Scientific: The Need for Predictive Models*. Oxford, UK: Oxford University Press.
- Taagepera, R. 2018. Science walks on two legs, but social sciences try to hop on one. *International Political Science Review* 39(1): 145-159.
- Taylor, R., P. 2015. *A Review of Industrial Restructuring in the Ruhr Valley and Relevant Points for China*. Available online: <http://www.iipnetwork.org/Industrial%20Restructuring%20in%20the%20Ruhr%20Valley.pdf>
- The Guardian. 08.03.2019. Norway's \$1tn wealth fund to divest from oil and gas exploration. <https://www.theguardian.com/world/2019/mar/08/norways-1tn-wealth-fund-to-divest-from-oil-and-gas-exploration>.
- The Guardian. 11.03.2019. Nearly all countries agree to stem flow of plastic waste into poor nations. <https://www.theguardian.com/environment/2019/may/10/nearly-all-the-worlds-countries-sign-plastic-waste-deal-except-us>.
- Turnheim, B., and Geels, F. W. 2013. The destabilisation of existing regimes: Confronting a multi-dimensional framework with a case study of the British coal industry (1913-1967). *Research Policy* 42(10): 1749-1767.
- Uyarra, E., Shapira, P., and Harding, A. 2016. Low carbon innovation and enterprise growth in the UK: Challenges of a place-blind policy mix. *Technological Forecasting & Social Change* 103: 264-272.
- Weber, K. M., and Rohracher, H. 2012. Legitimizing research, technology and innovation policies for transformative change: Combining insights from innovation systems and multi-level perspective in a comprehensive 'failures' framework. *Research Policy* 41(6): 1037-1047.
- Xu, L., and Su, J. 2016. From government to market and from producer to consumer: Transition of policy mix towards clean mobility in China. *Energy Policy* 96: 328-340.
- Zhao, Y., Xiao, G., Zhou, J., and Wu, C. 2017. International Comparison of the Patterns in Urban Transition towards Greening. *Procedia Engineering* 198: 770-780.

Appendix A. Coding protocol for the literature review

Coding guide

Each article was assessed along three dimensions:

- 1) completeness: presence of intervention points (from none to all 6);
- 2) clarity: whether the intervention points were explicit (stated clearly) or implicit (i.e., requiring considerable interpretive effort from the coder);
- 3) systematic treatment: whether the intervention points were covered systematically (i.e., they were part of the conceptual framework and/or empirical analysis of the article) or non-systematically (i.e., they were mentioned in the article but could not be considered part of the conceptual framework and/or the empirical analysis).

If the article contained at least one type of intervention point, it was coded according to the following scheme:

- 1** – the challenge is mentioned implicitly, but not covered systematically
- 2** – the challenge is mentioned explicitly, but not covered systematically
- 3** – the challenge is mentioned implicitly and covered systematically
- 4** – the challenge is mentioned explicitly and covered systematically

Coding results

Article search was performed on 10.05.2019. The publication details of each article have been amended to reflect their current status.

Article (N = 55)	Type					
	Challenge 1	Challenge 2	Challenge 3	Challenge 4	Challenge 5	Challenge 6
Auvinen, H., Ruutu, S., Tuominen, A., Ahlqvist, T., & Oksanen, J. (2014). <i>Process supporting strategic decision-making in systemic transitions. Technological Forecasting and Social Change</i> , 94, 97–114. https://doi.org/10.1016/j.techfore.2014.07.011	1	1				
Burke, M. J., & Stephens, J. C. (2017). <i>Energy democracy: Goals and policy instruments for sociotechnical transitions. Energy Research and Social Science</i> , 33(October), 35–48. https://doi.org/10.1016/j.erss.2017.09.024	2	2	2			
Capasso, M., Hansen, T., Heiberg, J., Klitkou, A., & Steen, M. (2019). <i>Green growth – A synthesis of scientific findings. Technological Forecasting and Social Change</i> , 146(June), 390–402. https://doi.org/10.1016/j.techfore.2019.06.013	2	2	2			
Chang, R., Cao, Y., Lu, Y., & Shabunko, V. (2019). <i>Should BIPV technologies be empowered by innovation policy mix to facilitate energy transitions? - Revealing stakeholders' different perspectives using Q methodology. Energy Policy</i> , 129(August 2018), 307–318. https://doi.org/10.1016/j.enpol.2019.02.047	4	4	4			

Cilinskis, E., Ziemele, J., Blumberga, A., & Blumberga, D. (2017). Analysis of support measures for promoting energy efficiency and renewables for GHG emissions reduction in non-ETS sector. <i>Energy Procedia</i> , 142, 2838–2843. https://doi.org/10.1016/j.egypro.2017.12.430					
Costantini, V., Crespi, F., Paglialunga, E., & Sforza, G. (2020). System transition and structural change processes in the energy efficiency of residential sector: Evidence from EU countries. <i>Structural Change and Economic Dynamics</i> , 53(June 2020), 309–329. https://doi.org/10.1016/j.strueco.2019.05.001	1	1			
David, M. (2017). Moving beyond the heuristic of creative destruction: Targeting exnovation with policy mixes for energy transitions. <i>Energy Research and Social Science</i> , 33(September), 138–146. https://doi.org/10.1016/j.erss.2017.09.023	1	1	4		
de Jesus, A., Antunes, P., Santos, R., & Mendonça, S. (2019). Eco-innovation pathways to a circular economy: Envisioning priorities through a Delphi approach. <i>Journal of Cleaner Production</i> , 228, 1494–1513. https://doi.org/10.1016/j.jclepro.2019.04.049	1	1			
Diercks, G. (2018). Lost in translation: How legacy limits the OECD in promoting new policy mixes for sustainability transitions. <i>Research Policy</i> , 48(10), 103667. https://doi.org/10.1016/j.respol.2018.09.002	1	1			4
Edmondson, D. L., Kern, F., & Rogge, K. S. (2019). The co-evolution of policy mixes and socio-technical systems: Towards a conceptual framework of policy mix feedback in sustainability transitions. <i>Research Policy</i> , 48(10), 103555. https://doi.org/10.1016/j.respol.2018.03.010	4	4	4		
Falcone, P. M., Lopolito, A., & Sica, E. (2017). Policy mixes towards sustainability transition in the Italian biofuel sector: Dealing with alternative crisis scenarios. <i>Energy Research and Social Science</i> , 33(September), 105–114. https://doi.org/10.1016/j.erss.2017.09.007	4	4	4		
Falcone, P. M., Lopolito, A., & Sica, E. (2018). The networking dynamics of the Italian biofuel industry in time of crisis: Finding an effective instrument mix for fostering a sustainable energy transition. <i>Energy Policy</i> , 112(November 2017), 334–348. https://doi.org/10.1016/j.enpol.2017.10.036	1	4			
Falcone, P. M., Lopolito, A., & Sica, E. (2019). Instrument mix for energy transition: A method for policy formulation. <i>Technological Forecasting and Social Change</i> , 148(May), 119706. https://doi.org/10.1016/j.techfore.2019.07.012	3	3			
Figenbaum, E. (2017). Perspectives on Norway's supercharged electric vehicle policy. <i>Environmental Innovation and Societal Transitions</i> , 25, 14–34. https://doi.org/10.1016/j.eist.2016.11.002	1	1	1		
Frank, A. G., Gerstlberger, W., Paslauskis, C. A., Lerman, L. V., & Ayala, N. F. (2018). The contribution of innovation policy criteria to the development of local renewable energy systems. <i>Energy Policy</i> , 115(January), 353–365. https://doi.org/10.1016/j.enpol.2018.01.036	1				
Geels, F. W., Schwanen, T., Sorrell, S., Jenkins, K., & Sovacool, B. K. (2018). Reducing energy demand through low carbon innovation: A sociotechnical transitions perspective and thirteen research debates. <i>Energy Research and Social Science</i> , 40(June 2017), 23–35. https://doi.org/10.1016/j.erss.2017.11.003	4	4			
Geels, F. W., Sovacool, B. K., Schwanen, T., & Sorrell, S. (2017). The Socio-Technical Dynamics of Low-Carbon Transitions. <i>Joule</i> , 1(3), 463–479. https://doi.org/10.1016/j.joule.2017.09.018	2	2	2	2	
Grubb, M., McDowall, W., & Drummond, P. (2017). On order and complexity in innovations systems: Conceptual frameworks for policy mixes in sustainability transitions. <i>Energy Research and Social Science</i> , 33(September), 21–34. https://doi.org/10.1016/j.erss.2017.09.016	2	2			
Hess, D. J., & Mai, Q. D. (2014). Renewable electricity policy in Asia: A qualitative comparative analysis of factors affecting sustainability transitions. <i>Environmental Innovation and Societal Transitions</i> , 12, 31–46. https://doi.org/10.1016/j.eist.2014.04.001	4	4			
Huttunen, S., Kivimaa, P., & Virkamäki, V. (2014). The need for policy coherence to trigger a transition to biogas production. <i>Environmental Innovation and Societal Transitions</i> , 12, 14–30. https://doi.org/10.1016/j.eist.2014.04.002	3	3			
Imbert, E., Ladu, L., Morone, P., & Quitzow, R. (2017). Comparing policy strategies for a transition to a bioeconomy in Europe: The case of Italy and Germany. <i>Energy Research and Social Science</i> , 33(March), 70–81. https://doi.org/10.1016/j.erss.2017.08.006	2	2	4		3
Ingold, K., Stadelmann-Steffen, I., & Kammermann, L. (2019). The acceptance of instruments in instrument mix situations: Citizens' perspective on Swiss energy transition. <i>Research Policy</i> , 48(10), 103694. https://doi.org/10.1016/j.respol.2018.10.018					

Janssen, M. J. (2019). What bangs for your buck? Assessing the design and impact of Dutch transformative policy. <i>Technological Forecasting and Social Change</i> , 138(August 2018), 78–94. https://doi.org/10.1016/j.techfore.2018.08.011	4	4	1			
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. <i>Energy Research and Social Science</i> , 33(February), 147–162. https://doi.org/10.1016/j.erss.2017.09.005	1	1	4			
Kern, F., & Rogge, K. S. (2018). Harnessing theories of the policy process for analysing the politics of sustainability transitions: A critical survey. <i>Environmental Innovation and Societal Transitions</i> , 27(June 2017), 102–117. https://doi.org/10.1016/j.eist.2017.11.001	2	2	2			
Kern, F., & Smith, A. (2008). Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. <i>Energy Policy</i> , 36(11), 4093–4103. https://doi.org/10.1016/j.enpol.2008.06.018	4	4	4			
Kern, F., Rogge, K. S., & Howlett, M. (2019). Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies. <i>Research Policy</i> , 48(10), 103832. https://doi.org/10.1016/j.respol.2019.103832	2	2	2			
Kitzing, L., Fitch-Roy, O., Islam, M., & Mitchell, C. (2020). An evolving risk perspective for policy instrument choice in sustainability transitions. <i>Environmental Innovation and Societal Transitions</i> , 35(June 2020), 369–382. https://doi.org/10.1016/j.eist.2018.12.002	1					
Kivimaa, P., & Kern, F. (2016). Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. <i>Research Policy</i> , 45(1), 205–217. https://doi.org/10.1016/j.respol.2015.09.008	4	4	4			
Kivimaa, P., Kangas, H. L., & Lazarevic, D. (2017). Client-oriented evaluation of 'creative destruction' in policy mixes: Finnish policies on building energy efficiency transition. <i>Energy Research and Social Science</i> , 33(September), 115–127. https://doi.org/10.1016/j.erss.2017.09.002	4	4	4			1
Lazarevic, D., Kautto, P., & Antikainen, R. (2020). Finland's wood-frame multi-storey construction innovation system: Analysing motors of creative destruction. <i>Forest Policy and Economics</i> , 110(January 2020), 101861. https://doi.org/10.1016/j.forpol.2019.01.006	4	4	4			
Lindberg, M. B., Markard, J., & Andersen, A. D. (2018). Policies, actors and sustainability transition pathways: A study of the EU's energy policy mix. <i>Research Policy</i> , 48(10), 103668. https://doi.org/10.1016/j.respol.2018.09.003	4	4	4			
Moore, T., Horne, R., & Morrissey, J. (2014). Zero emission housing: Policy development in Australia and comparisons with the EU, UK, USA and California. <i>Environmental Innovation and Societal Transitions</i> , 11, 25–45. https://doi.org/10.1016/j.eist.2013.12.003						
Ossenbrink, J., Finnsson, S., Bening, C. R., & Hoffmann, V. H. (2019). Delineating policy mixes: Contrasting top-down and bottom-up approaches to the case of energy-storage policy in California. <i>Research Policy</i> , 48(10), 103582. https://doi.org/10.1016/j.respol.2018.04.014	2	2	2			
Purkus, A., Gawel, E., & Thrän, D. (2017). Addressing uncertainty in decarbonisation policy mixes – Lessons learned from German and European bioenergy policy. <i>Energy Research and Social Science</i> , 33(February), 82–94. https://doi.org/10.1016/j.erss.2017.09.020	4	4		1		
Purkus, A., Hagemann, N., Bedtke, N., & Gawel, E. (2018). Towards a sustainable innovation system for the German wood-based bioeconomy: Implications for policy design. <i>Journal of Cleaner Production</i> , 172, 3955–3968. https://doi.org/10.1016/j.jclepro.2017.04.146	4	4				
Quitow, R. (2015). Assessing policy strategies for the promotion of environmental technologies: A review of India's National Solar Mission. <i>Research Policy</i> , 44(1), 233–243. https://doi.org/10.1016/j.respol.2014.09.003	2					
Raven, R., & Walrave, B. (2018). Overcoming transformational failures through policy mixes in the dynamics of technological innovation systems. <i>Technological Forecasting and Social Change</i> , 153(April 2020), 119297. https://doi.org/10.1016/j.techfore.2018.05.008	4	4	4			
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. <i>Technological Forecasting and Social Change</i> , 106, 11–21. https://doi.org/10.1016/j.techfore.2016.01.029	2	2				
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. <i>Renewable and Sustainable Energy Reviews</i> , 80(June), 1217–1226. https://doi.org/10.1016/j.rser.2017.05.280	2	2				

Roesler, T., & Hassler, M. (2019). <i>Creating niches – The role of policy for the implementation of bioenergy village cooperatives in Germany</i> . <i>Energy Policy</i> , 124(August 2019), 95–101. https://doi.org/10.1016/j.enpol.2018.07.012	4					
Rogge, K. S., & Dütschke, E. (2018). <i>What makes them believe in the low-carbon energy transition? Exploring corporate perceptions of the credibility of climate policy mixes</i> . <i>Environmental Science and Policy</i> , 87(June), 74–84. https://doi.org/10.1016/j.envsci.2018.05.009	4	4	4			
Rogge, K. S., & Johnstone, P. (2017). <i>Exploring the role of phase-out policies for low-carbon energy transitions: The case of the German Energiewende</i> . <i>Energy Research and Social Science</i> , 33(September), 128–137. https://doi.org/10.1016/j.erss.2017.10.004	4	4	4			
Rogge, K. S., & Reichardt, K. (2016). <i>Policy mixes for sustainability transitions: An extended concept and framework for analysis</i> . <i>Research Policy</i> , 45(8), 1620–1635. https://doi.org/10.1016/j.respol.2016.04.004	3	3				
Rogge, K. S., & Schleich, J. (2018). <i>Do policy mix characteristics matter for low-carbon innovation? A survey-based exploration of renewable power generation technologies in Germany</i> . <i>Research Policy</i> , 47(9), 1639–1654. https://doi.org/10.1016/j.respol.2018.05.011	4	4				
Rogge, K. S., Kern, F., & Howlett, M. (2017). <i>Conceptual and empirical advances in analysing policy mixes for energy transitions</i> . <i>Energy Research and Social Science</i> , 33(October), 1–10. https://doi.org/10.1016/j.erss.2017.09.025	4	4	4			
Rogge, K. S., Pfluger, B., & Geels, F. W. (2020). <i>Transformative policy mixes in socio-technical scenarios: The case of the low-carbon transition of the German electricity system (2010–2050)</i> . <i>Technological Forecasting and Social Change</i> , 151(February 2020), 119259. https://doi.org/10.1016/j.techfore.2018.04.002	4	4	4			
Rosenow, J., Kern, F., & Rogge, K. (2017). <i>The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: The case of energy efficiency policy</i> . <i>Energy Research and Social Science</i> , 33(March), 95–104. https://doi.org/10.1016/j.erss.2017.09.013	1	1				
Schmidt, T. S., & Sewerin, S. (2019). <i>Measuring the temporal dynamics of policy mixes – An empirical analysis of renewable energy policy mixes' balance and design features in nine countries</i> . <i>Research Policy</i> , 48(10), 103557. https://doi.org/10.1016/j.respol.2018.03.012	2	2	2			
Scordato, L., Klitkou, A., Tarti, V. E., & Coenen, L. (2018). <i>Policy mixes for the sustainability transition of the pulp and paper industry in Sweden</i> . <i>Journal of Cleaner Production</i> , 183, 1216–1227. https://doi.org/10.1016/j.jclepro.2018.02.212	4	4	4			
Skjølsvold, T. M., & Ryghaug, M. (2020). <i>Temporal echoes and cross-geography policy effects: Multiple levels of transition governance and the electric vehicle breakthrough</i> . <i>Environmental Innovation and Societal Transitions</i> , 35(June 2020), 232–240. https://doi.org/10.1016/j.eist.2019.06.004	4	4	4			
Söderholm, P., Hellsmark, H., Frishammar, J., Hansson, J., Mossberg, J., & Sandström, A. (2019). <i>Technological development for sustainability: The role of network management in the innovation policy mix</i> . <i>Technological Forecasting and Social Change</i> , 138(August 2018), 309–323. https://doi.org/10.1016/j.techfore.2018.10.010	2	2	2			
Trencher, G., & van der Heijden, J. (2019). <i>Instrument interactions and relationships in policy mixes: Achieving complementarity in building energy efficiency policies in New York, Sydney and Tokyo</i> . <i>Energy Research and Social Science</i> , 54(October 2018), 34–45. https://doi.org/10.1016/j.erss.2019.02.023						
Uyarra, E., Shapira, P., & Harding, A. (2016). <i>Low carbon innovation and enterprise growth in the UK: Challenges of a place-blind policy mix</i> . <i>Technological Forecasting and Social Change</i> , 103, 264–272. https://doi.org/10.1016/j.techfore.2015.10.008	2	2				
Wils, H., & O'Brien, M. (2019). <i>A Policy Mix for Resource Efficiency in the EU: Key Instruments, Challenges and Research Needs</i> . <i>Ecological Economics</i> , 155(May 2018), 59–69. https://doi.org/10.1016/j.ecolecon.2018.05.004				2		

3. Coding examples

The following presents excerpts from articles with brief explanations from the coder showing how the coding scheme was applied. All emphases are portrayed in quotes (bold) and have been added by authors.

3.1 The challenge is mentioned implicitly, but not covered systematically

In these instances policy mixes were not connected to the intervention point in a clear manner but could be interpreted as belonging to one or another. Furthermore, the implied intervention point was not part of the main idea of the article but rather remained an occasional comment.

Example 1: “**Promoting more costly and complex niche technology** also implies incentives for innovation and this results in cost-reductions in the future through learning-by-doing that can ultimately lead to ‘industrialisation’ of more complex energy efficiency technologies” (Figenbaum, 2017: 14).

Explanation: The quote uses the term ‘niche’ to make a particular point about the need to promote complex technologies. Although not explicitly spelled out as such the excerpt could be interpreted as hinting at the importance of niche stimulation. It has been coded as non-systematic because the overall focus of the article is on the comprehensiveness and cost of instrument mixes.

Example 2: “We understand policy mix as the combination of government policy instruments which, by design or fortune, **have direct or indirect impact on the quantity and quality of research and development (R&D) investments** in public and private sectors for the purpose of developing innovation systems” (Frank et al., 2018: 354-355).

Explanation: The quote alludes to the importance of using policy mixes for stimulating niches through R&D without, however, using specific transitions vocabulary. Furthermore, this idea is not central to the article which discusses innovation policy criteria in relation to local renewable energy systems.

3.2 The challenge is mentioned explicitly, but not covered systematically

In these instances policy mixes were explicitly connected to a particular intervention point. However, the intervention point was not part of the main focus of the article but rather remained more peripheral or occasional.

Example 1: “Besides market failures, clean technologies often face multiple systemic and institutional failures (Bleda and del Río, 2013; Foxon et al., 2005; Rip and Kemp, 1998; Unruh, 2000), including barriers to adoption, switching costs, and insufficient network effects, and thus their adoption requires organizational and institutional change. **A challenge is thus how to avoid carbon lock-in (Unruh, 2000) and facilitate transitions towards more sustainable ‘regimes’ (Geels, 2002; Markard et al., 2012; Smith et al., 2010) by nurturing and scaling up alternative technological niches** that are not yet sufficiently competitive or proven” (Uyarra et al., 2016: 265).

Explanation: In this example niche stimulation and acceleration are explicitly addressed, but neither constitute the focal point of the article which analyses UK's policy support for innovation in low carbon manufacturing sectors.

Example 2: “We [...]define policy mixes as the specific combinations of policy instruments which interact explicitly or implicitly in fostering (low-energy) innovations and **disrupting dominant (high-energy) regimes**” (Burke and Stephens, 2017: 16).

Explanation: In this example, the need for destabilizing existing regimes is explicit, but this is not the focal point of the article which discusses different approaches to policy mix analyses.

3.3 The challenge is mentioned implicitly and covered systematically

In these instances policy mixes were not clearly connected to particular intervention points but could be interpreted as such. However, the implied intervention point was a part of the conceptual framework and/or empirical analysis of the article.

Example 1: “Therefore, in Table 2 we propose a more balanced 3×3 matrix typology that combines three instrument types (economic instruments, regulation and information) with three instrument purposes (**technology push, demand pull** and systemic concerns)” (Rogge and Reichardt, 2016: 1623).

Explanation: This is one of the examples that mentions both technology push and demand pull. These were codified as hinting at the importance of niche stimulation and acceleration (without using the specific transitions terminology). Both ideas are also essential to the article devoted to discussing policy mixes for sustainability transitions.

Example 2: “As elements of the two strategies are **“uploaded” to the European level**, they offer opportunities for diffusion and **reinforcement via various EU policies and programs**” (Imbert et al., 2017: 79).

Explanation: The article analyses how German and Italian bioeconomy policies have influenced each other through policy making on the European Union level. Although not using the specific terminology it can be interpreted as systematically addressing the need to tilt the landscape.

3.4 The challenge is mentioned explicitly and covered systematically

In these instances policy mixes were explicitly connected to particular intervention points and could be considered a part of the conceptual framework and/or empirical analysis of the article.

Example 1: “Strategic niches where innovation occurs, such as solar energy, **require government protection and support, at least until they are able to scale up** and to achieve pricing parity or until policy internalizes externalities of competing technologies through instruments such as carbon pricing” (Hess and Mai, 2014: 32).

Explanation: In this quote the need for niche acceleration is made explicit. The topic constitutes a central part of the article which discusses sustainability transitions and renewable electricity policy in Asia.

Example 2: “**Such destruction policies include control policies** (e.g. carbon pricing or regulatory restrictions), **significant changes to regime rules** (e.g. electricity market reform), **reduced support for dominant regime technologies** (e.g. reduction of subsidies for fossil fuels) and changes in social networks, for example by the replacement of key actors in stakeholder consultations or empowerment of new entrants in political debates (Kivimaa and Kern, 2016). In addition, policies can also **support the destruction** side of transitions by **enabling changes in the organisational and institutional practices** of policy making processes (Kivimaa et al., 2017b)” (Rogge et al., 2018: 2-3).

Explanation: Destabilization of the regime is explicitly mentioned in the excerpt. The article is about policy mixes for low-carbon transition of the German electricity system and regime destabilization is a central element of the article.