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Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions

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ABSTRACT

Recently, there has been an increasing interest in policy mixes in innovation studies. While it has long been acknowledged that the stimulation of innovation and technological change involves different types of policy instruments, how such instruments form policy mixes has only recently become of interest. We argue that an area in which policy mixes are particularly important is the field of sustainability transitions. Transitions imply not only the development of disruptive innovations but also of policies aiming for wider change in socio-technical systems. We propose that ideally policy mixes for transitions include elements of 'creative destruction', involving both policies aiming for the 'creation' of new and for 'destabilising' the old. We develop a novel analytical framework including the two policy mix dimensions ('creation' and 'destruction') by broadening the technological innovation system functions approach, and specifically by expanding the concept of 'motors of innovation' to 'motors of creative destruction'. We test this framework by analysing 'low energy' policy mixes in Finland and the UK. We find that both countries have diverse policy mixes to support energy efficiency and reduce energy demand with instruments to cover all functions on the creation side. Despite the demonstrated need for such policies, unsurprisingly, destabilising functions are addressed by fewer policies, but there are empirical examples of such policies in both countries. The concept of 'motors of creative destruction' is introduced to expand innovation and technology policy debates to go beyond policy mixes consisting of technology push and demand pull instruments, and to consider a wider range of policy instruments combined in a suitable mix which may contribute to sustainability transitions.

1. Introduction

Recently, there has been increasing interest in the innovation studies literature in questions surrounding policy mixes. While it has long been acknowledged that the stimulation of innovation and technological change can include a number of different types of policy instruments and that the most appropriate type of instrument might depend on the stage of the innovation process or the respective sector (Pavitt, 1984), the issue of how such instruments form policy mixes has only recently been highlighted as being of interest to this community (Flanagan et al., 2011; Borrás and Edquist, 2013; Magro and Wilson, 2013; Quitzow, 2015) as well as policy makers from the European Commission (Nauwelaers et al., 2009).

We argue that policy mixes are particularly important in the field of sustainability transitions. This literature has received increasing interest in the context of technology and innovation studies and goes beyond single innovations, examining change at the level of socio-technical systems (cf. Markard et al., 2012). Transitions in the form of systemic changes in current structures for consumption and production are viewed as being of paramount importance to reduce the overall environmental impacts of human activities. Much of the literature focusses either on protective niche spaces for innovations which might overturn incumbent regimes (Smith and Raven, 2012) or on facilitating the emergence of technological innovation systems (e.g. Bergek et al., 2008). Recently, attention has also been paid to the processes of destabilising incumbent regimes through "weakening reproduction of core regime elements" that are seen as necessary to create "windows of opportunity" for the upscaling of niche innovations (Turnheim and

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Geels, 2012, 2013). In this context, major policy change has been argued to be important, because "it shapes both the direct support for industries... and economic frame conditions" (Turnheim and Geels, 2012, p. 46). Thus, transitions may not only require the development of disruptive innovations but also of disruptive policy mixes aiming for systemic change (e.g. Kivimaa and Virkamäki, 2014; Weber and Rohracher, 2012). This type of policy change is often, however, constrained by the political challenges of introducing more coherent policy mixes (Howlett and Rayner, 2007; Kern and Howlett, 2009).

Building on the seminal concept of creative destruction, proposed by Joseph Schumpeter, and the recent concept of regime destabilisation (Turnheim and Geels, 2012), we propose that policy mixes favourable to sustainability transitions need to involve both policies aiming for the 'creation' of new and for 'destroying' (or withdrawing support for) the old. By making this distinction we want to ease the identification of elements potentially lacking in existing policy mixes from the perspective of transitions. Moreover, the urgency of sustainability transitions requires explicit analyses of active destabilisation, because solely relying on the emergence and growth of a variety of alternatives to replace incumbent systems will be too slow. We conceive of these kinds of policy mixes as not only comprising typical innovation and technology policies but all policies that potentially work in favour of transitions.

This paper extends the work on the functions of Technological Innovation Systems (TIS) by proposing a novel conceptual framework for policy mixes for sustainability transitions, and introducing it as "motors of creative destruction" building on and extending Suurs and Hekkert's (2009) concept of "motors of innovation". The extension addresses a previous critique of the TIS approach (e.g. Smith and Raven, 2012; Kern, 2015) that it does not pay enough attention to the regime level for analysing transitions. While the idea of destabilising regimes may be implicit in TIS through its intended key contribution to function as a tool for identifying system weaknesses preventing a specific TIS from developing (e.g. Jacobsson and Bergek, 2011), the development of a new TIS does not automatically lead to 'destruction' in the dominant regime. Moreover, destabilisation can serve the upscaling of several TISs in different subsystems, not just a specific one. Therefore, we combine attention to supporting the development of specific niche innovations and new technological innovation systems with attention to regime destabilisation, and argue that policy mixes need to attend to both processes in a mutually re-enforcing way. Empirical testing of the framework is provided by examining policy mixes influencing low energy transitions in Finland and the UK. Both countries have made significant efforts to promote energy efficiency but provide interesting contrasts in several ways (discussed later).

The next section reviews the literature before Section 3 turns to the proposed analytical framework and the methodology. Section 4 presents the empirical analysis followed by a discussion of the key insights in Section 5 and conclusions in Section 6.

2. Innovation policy mixes and sustainability transitions

2.1. Policy mixes

Recent interest in innovation policy mixes has been justified on the grounds that real world policy contexts involve several policy instruments in different policy domains and with different rationales, dispersed governance structures and many levels of administration (Flanagan et al., 2011; Borrás and Edquist, 2013; Magro and Wilson, 2013; Quitzow, 2015). Many scholars use the concept of 'policy mix' similarly to Borrás and Edquist (2013, p. 1514) who refer to 'a set of different and complementary policy instruments to address the problems identified' in a national or regional innovation system. However, broader interpretations have been suggested by Magro and Wilson (2013) and Rogge and Reichardt (2013), adding to the mix also policy goals and rationales as well as processes of policy making and implementation. While we see merit in the broader concept of the policy mix, for purposes of empirical illustration in this paper, we focus on what Rogge and Reichardt (2013) would define as instrument mixes. We do, however, extend from Borrás and Edquist in that we examine policy mixes for transitions over several policy domains, not merely 'classic' innovation policy instruments. Analyses across domains are important from the perspective of policy coherence and consistency, as sub-optimal or even perverse outcomes of policies can frequently be explained by clashing policies designed for different purposes across different policy domains (e.g. Huttunen et al., 2014; Nilsson et al., 2012).

Howlett and Rayner (2007) have explained the complexity of policy mixes developing over time in non-innovation policy contexts. They define three kinds of policy mix evolution: *layering* that indicates new goals and instruments added on top of existing ones, often leading to incoherent and inconsistent mixes; *drift* to imply changed policy goals without altering the instruments, creating inconsistency between them, and; *conversion* denoting change in instruments without altering goals. A fourth type is introduced by Kern and Howlett (2009) as *replacement* that fundamentally restructures both goals and instruments in a conscious, coherent and consistent manner. However, Howlett and Rayner (2013, p. 177) note that most existing policy mixes have developed through "*layering, or repeated bouts of policy conversion or policy drift*", often resulting in inconsistent policy mixes, and that situations where new consistent policy mixes are developed are rather rare. Similarly, in the context of innovation studies, Flanagan et al. (2011) have argued that policy mixes can at best be coordinated by a process of mutual adjustment between a variety of actors and systems. This means that there are no 'optimal' (Nauwelaers et al., 2009; Borrás and Edquist, 2013; Quitzow, 2015) or even 'good' (Flanagan et al., 2011) innovation policy mixes in a general sense.

Our contribution complements many recent studies on innovation policy mixes (e.g. Flanagan et al., 2011; Borrás and Edquist, 2013; Rogge and Reichardt, 2013) that are predominantly conceptual (the exception being Quitzow, 2015), by applying the concept of an innovation policy mix to an empirical context. We also address other shortcomings in this literature: the consideration of innovation fairly narrowly in the context of R&D support, firms and individual technologies (e.g. Nauwelaers et al., 2009; Rogge and Reichardt, 2013; Quitzow, 2015) and the lack of attention to policy mixes fostering 'directed' transitions towards more sustainable socio-technical systems. The need for such transitions is a crucial policy challenge and an increasing focus of academic research, reviewed below.

2.2. Sustainability transitions and innovation policy

Considerable recent literature on sustainability transitions has emerged to study the transformation of socio-technical systems (incl. technologies, infrastructures, institutions, industrial sectors, user behaviours) towards environmental sustainability. The multi-level perspective (MLP) has developed as a key meso-theory to explain such processes (Markard et al., 2012). The principal idea of the MLP is that transitions come about through interactions between three different levels: landscape (macro-economic and macro-political trends, significant environmental changes, demographic trends, etc.), regime (the deep structure of the socio-technical system involving alignment between technologies, infrastructure, institutions, practices, behavioural patterns, markets, industry structures, etc.), and niches (spaces where various technical, social and organisational innovations are created and tested) (Geels, 2002, 2004, 2011; Geels and Schot, 2007). The MLP posits that top-down landscape pressures and bottom-up developments of several emerging niches can lead to the destabilisation of incumbent regimes offering opportunities for niches to break through and overthrow the incumbent regime. Closely connected to the MLP (Rip and Kemp, 1998) and developing at the same time, the literature on Strategic Niche Management (SNM) has emerged as a call to extend technology policy to facilitate the development of technological niches through experimentation-oriented policy tools, potentially stimulating transitions towards new regimes (Kemp et al., 1998; Hoogma et al., 2002). Raven (2005) has linked niche development and increased niche market size to the instability of regimes.

A related theoretical trajectory is that of Technological Innovations Systems (TIS), developed to study the emergence of new technologies and the formation of technology-specific innovation systems around them, and particularly to identify "system weaknesses that should be tackled by public policy" (Jacobsson and Bergek, 2011, p. 46). Many recent TIS studies are focused on system functions that are defined as processes influencing the development of an innovation system around a particular technology (Suurs and Hekkert, 2009; Jacobsson and Bergek, 2011). The central idea behind the TIS functions approach is that, through cumulative causation, the different functions strengthen one another and together lead to a positive, self-reinforcing dynamic ('motors of innovation') allowing a technology-specific innovation system to develop (Suurs and Hekkert, 2009). Suurs and Hekkert (2009) have found national policy to support mainly the 'science and technology push' motor and to have hampering effects on market and entrepreneurial motors. The motors are argued to enable the build-up of TIS; they emerge over a long period of time and comprise a broad variety of activities (Suurs and Hekkert, 2009).

In comparison to MLP/SNM, little insight has been provided on how an emerging TIS can overturn incumbent regimes, a shortcoming pointed out by Markard and Truffer (2008) and Smith and Raven (2012). This is because the starting point for (many) TIS analyses is the dynamics of a specific TIS, while sector or regime level dynamics are backgrounded. Whereas the identification of technological innovation system weaknesses is described as a core concept (Jacobsson and Bergek, 2011), the wider sectoral system or regime has rarely been explicitly addressed by the empirical TIS studies published over the last couple of years. More importantly, as the TIS framework was designed to capture factors (including those at the sectoral level) that influence the functional pattern of a specific TIS, it cannot be expected to identify the full range of sources of inertia that destabilising functions need to address in a given sector or regime. Our contribution is, therefore, to extend the TIS framework to shed light on the functions needed not only for the support of new innovations but also for the destabilisation of existing regimes; our argument being that policy mixes need to explicitly attend to both processes in a mutually re-enforcing way. This complements the recent papers that discussed innovation policy in the context of socio-technical transitions (Alkemade et al., 2011; Weber and Rohracher, 2012; Meelen and Farla, 2013; Kivimaa and Virkamäki, 2014).

The existing transitions literature acknowledges that governing sustainability transitions is a political project in which the direction of travel and the means are often highly contested (Shove and Walker, 2007; Meadowcroft, 2009; Scrase and Smith, 2009). Different governments engage with the challenges of accelerating sustainability transitions in quite different ways (Kern, 2011) and not all policy recipes travel well to other political contexts (Heiskanen et al., 2009). Because "[c]hoices among alternative technological pathways involve [political] struggles among rival commercial groups... And politics and governments are inevitably preoccupied with managing the distributional fall out" (Meadowcroft, 2011, p. 71), the resulting policy mixes are likely to be political compromises. This point about the distributional effects is particularly pertinent when discussing policy mixes for the explicit destabilisation of regimes. While the politics behind particular policy choices are an important part of socio-technical transitions generally, this issue falls outside the core focus of this paper as we will argue in Section 3.

2.3. Policy mixes for creative destruction?

The idea of sustainability transitions as being partly enabled by the destabilisation of established socio-technical regimes (e.g. Turnheim and Geels, 2013) links to the concept of creative destruction, as coined by Joseph Schumpeter. Creative destruction has been conceptualised as a process, in which an innovative entrepreneur challenges incumbent firms and technologies in a way that makes the existing technologies obsolete, forcing incumbents to withdraw from the market (Soete and ter Weel, 1999). At the heart of the entrepreneurial action is disruptive and competence destroying innovation (Christensen, 1997; Tushman and Anderson, 1986) that "changes the technology of process or product in a way that imposes requirements that the existing resources, skills and knowledge satisfy poorly or not at all. The effect is thus to reduce the value of existing competence, and in the extreme case, to render it obsolete" (Abernathy and Clark, 1985, p. 6). However, critics also point to empirical evidence which shows that, through processes of creative accumulation, incumbents may be able to absorb new technologies and integrate them within their existing capabilities and thereby prevent the destruction of existing industries as a consequence of discontinuous technological change (Bergek et al., 2013). We suggest that a similar kind of thinking as implied by 'disruptive innovation' could be applied to policy in that policies could be disruptive in the institutional context shaking the regime in a way that reduces the value of existing practices and technologies, thereby creating momentum for transitions and maybe also incentivising incumbents to play an active role in the transformation. We argue that attention to the destruction side is particularly relevant when alternative innovations have already developed some momentum rather than being at a very early stage. We further specify this thinking by developing a novel analytical framework in Section 3.1 extending the TIS functions approach.

3. Analytical framework and methodology

3.1. Analytical framework: policy mixes for sustainability transitions through 'creative destruction'

Building on the literature reviewed above, the focus of our analytical framework is on policy instruments or measures targeting two different types of processes that have been highlighted to be of importance for sustainability transitions: the creation of niche innovations including their development over time and the destruction of incumbent regimes (Table 1). On the 'creative' side, we mainly use the existing TIS functions as a basis (Bergek et al., 2008; Jacobsson and Bergek, 2011) as it gives a rather comprehensive list of innovation-inducing processes that policies can potentially address (Kivimaa and Virkamäki, 2014), and make slight amendments influenced by the SNM literature.[1] We added

[1] Positive externalities has been identified as one of the seven TIS components, and may, for example, hinder private R&D investments due to 'free' knowledge spillovers to other actors (e.g. Jacobsson and Bergek, 2011). It is, however, not included in our analytical framework as it partly involves public R&D funding, which is well covered in the categories for knowledge (C1) and resource mobilisation (C5) already. Second, Bergek et al. (2008, p. 418) themselves argue that "[t]his function is thus

Table 1
The analytical framework.

Potential innovation/system influence of policy instrument	Basis in literature	Description of policy instruments (influenced by Kivimaa and Virkamäki, 2014)
Creative (niche support)		
Knowledge creation, development and diffusion (C1)	Strengthening the knowledge base and how that knowledge is developed, combined and diffused is a key TIS function and a key process within the SNM literature (learning). This implies not only R&D but support for networks as network weaknesses can hinder knowledge development (Jacobsson and Bergek, 2011). Different types of knowledge, e.g. scientific, technological, production, market, logistics and design, and sources of knowledge, e.g. R&D and learning, are included (Bergek et al., 2008).	R&D funding schemes, innovation platforms and other policies aiming to increase knowledge creation and diffusion through networks; subsidies for demonstrations; educational policies, training schemes, coordination of intellectual property rights, reference guidelines for best available technology.
Establishing market niches/market formation (C2)	Strengthening market formation by creating new customer demand, e.g. through institutional change, is also a TIS function. It comprises niche markets, e.g. in the form of demonstration projects, bridging markets and mass markets (Jacobsson and Bergek, 2011). Also in SNM, niche markets are considered important for the further development of new socio-technical configurations (Hoogma et al., 2002). They can be created through policy action but also might pre-exist in the form of green consumers who buy products with sustainability credentials despite higher prices or lower performance (Smith and Raven, 2012).	Regulation, tax exemptions, market-based policy instruments such as certificate trading, feed-in tariffs, public procurement, deployment subsidies, labelling.
Price-performance improvements (C3)	According to the SNM literature, sustainable innovations are often not competitive within normal selection environments because their performance is weaker compared to incumbent technologies (e.g. electric cars in terms of range) and/or their price is higher (e.g. wind compared to natural gas) (Schot and Geels, 2008). Through achieving price-performance improvements, niches can over time become competitive with incumbent technologies and this process can be aided by policy (Kern, 2012). C1 and C2 also influence C3.	Deployment and demonstration subsidies enabling learning-by-doing; R&D support (cost reductions through learning).
Entrepreneurial experimentation (C4)	In TIS, this involves the reduction of uncertainties as a consequence of the testing of new technologies, applications and markets to enable piloting, the creation of new opportunities and learning (Bergek et al., 2008; Jacobsson and Bergek, 2011). It also involves support for entrepreneurship, e.g. through innovative policy designs, addressing partly the formation of new actors and networks in SNM.	Policies stimulating entrepreneurship and diversification of existing firms, advice systems for SMEs, incubators, low-interest company loans, venture capital; relaxed regulatory conditions for experimenting.
Resource mobilisation (C5)	Mobilisation of human and financial capital, and complementary assets such as network infrastructure are included in this TIS function (Bergek et al., 2008; Jacobsson and Bergek, 2011).	Financial: R&D funding, deployment subsidies, low-interest loans, venture capital. Human: educational policies, labour-market policies, secondment of expertise.
Support from powerful groups/legitimation (C6)	"Legitimacy, i.e. social acceptance and compliance with relevant institutions; is needed for many of the other functions to work, e.g. for resources to be mobilized, for markets to form and for actors to acquire political strength. Legitimacy also influences expectations among managers and, by implication, the function "influence on the direction of search"" (Jacobsson and Bergek, 2011, p. 51). In SNM, shared positive expectations legitimate the continuation of protecting and nurturing a niche (Schot and Geels, 2008).	Innovation platforms, foresight exercises, public procurement and labelling to create legitimacy for new technologies, practices and visions.
Influence on the direction of search (C7)	TIS defines this as incentives and/or pressures for organisations to enter into the technological field influenced by visions and expectations articulated by companies and in policies (e.g. Jacobsson and Bergek, 2011), by landscape changes, and by legitimisation (Bergek et al., 2008). Links also the articulation of expectations and visions in SNM (e.g. Smith and Raven, 2012). Conflicting policy goals and instruments are likely to diminish this influence.	Goals set and framing in strategies, targeted R&D funding schemes, regulations, tax incentives, foresight exercises, voluntary agreements.
Destruction (regime destabilisation)		
Control policies (D1)	The transition management literature argues that 'control policies' are required to put pressure on the regime. For example internalising the environmental costs of carbon emissions is argued to be key to create an 'extended level playing field' for niches and incumbent technologies to compete on fair terms (van den Bergh et al., 2006). Kemp and Rotmans argue that without such policies the fostering of niche innovations will not lead to transitions (Kemp and Rotmans, 2004, p. 164).	Policies, such as taxes, import restrictions, and regulations. Control policies, for example, may include using carbon trading, pollution taxes or road pricing to put economic pressure on current regimes. Banning certain technologies is the strongest form of regulatory pressure (e.g. phase out of fluorescent light bulbs).

Table 1 (*Continued*)

Potential innovation/system influence of policy instrument	Basis in literature	Description of policy instruments (influenced by Kivimaa and Virkamäki, 2014)
Significant changes in regime rules (D2)	The 'deep structure' of socio-technical regimes consists of semi-coherent set of rules directing and coordinating the activities of the social groups reproducing the various elements of socio-technical systems; one element of destabilisation can be reconfiguration in the institutional rules which are favourable to the status quo/path dependent evolution of the regime (Geels, 2011). Particularly, radical policy reforms, where policies substantially change economic frame conditions, may accelerate destabilisation (Turnheim and Geels, 2012, p. 44).	Policies constituting, for example, structural reforms in legislation or significant new overarching laws. Historic examples of major rule changes include the privatisation and liberalisation of electricity markets in the 1990s which completely changed the selection environment within which utilities were operating.
Reduced support for dominant regime technologies (D3)	Support for incumbent technologies can become institutionalised within the rules of the regimes which make it difficult for innovations to break through (Smith and Raven, 2012). For example fossil fuel technologies are heavily subsidised and "their removal would greatly contribute to their destabilisation"(Turnheim and Geels, 2012, p. 48). Historical examples show that the loss of support can have serious consequences (Turnheim and Geels, 2012), and that radical innovation in technology implies a changed balance between a process or a product and existing resources (Abernathy and Clark, 1985).	Withdrawing support for selected technologies (e.g. cutting R&D funding, removing subsidies for fossil fuel production or removing tax deductions for private motor transport).
Changes in social networks, replacement of key actors (D4)	Close relationships between government and key regime actors is often seen as a major source of lock-in (Unruh, 2000; Walker, 2000). Regime destabilisation may involve replacement of incumbents by new actors (Turnheim and Geels, 2012). Similarly creative destruction involves replacing existing skill and knowledge (of actors) with new ones (Abernathy and Clark, 1985). Deliberately breaking up established actor-network structures or developing different fora to bypass traditional policy networks could provide windows of opportunity for niche innovations and is one of the strategies recommended by transition management scholars (Rotmans et al., 2001).	Balancing involvement of incumbents for example in policy advisory councils with niche actors (as attempted in the Dutch energy transition programme through the transition platforms) (Kern and Smith, 2008); formation of new organisations or networks to take on tasks linked to system change.

'price-performance improvements' as an additional category, because the SNM literature argues that price-performance improvements are an important process that helps stabilise a niche and enables it to compete with incumbent technologies (Geels and Schot, 2007).

Our analytical categories on the 'destruction' side are developed drawing particularly on the concepts of regime (e.g. Hoogma et al., 2002; Geels, 2010) and destabilisation (Turnheim and Geels, 2012, 2013). We also link these to creative destruction and disruptive innovation (Abernathy and Clark, 1985) and some of the ideas of transition management (Rotmans et al., 2001; Kemp and Rotmans, 2004).

What do we know about how existing regimes can be unsettled? Technological regimes have been conceptualised to be about rules, i.e. the cognitive and normative framework connected to functional relationships between technical components and actors (Hoogma et al., 2002, p. 19). It is both the technology and the rules in the regimes that have frequently been identified to be path dependent and, therefore, difficult to change (Unruh, 2000; Pierson, 2004). The struggle between niches (creation and development of the new) and regimes (stability of the old 'dominant design' (Anderson and Tushman, 1990)[2] supported by incremental innovation (c.f. Abernathy and Clark, 1985)) has been argued to happen around dimensions such as markets, regulations and infrastructure, and the politics around them, and being enacted by various actors building coalitions, when navigating transitions (Geels, 2010; Meadowcroft, 2011).

In the literature linked to creative destruction, the struggle has been described to occur particularly after disruptive innovation has emerged. The struggle is portrayed as competition between old and new technical regimes during the 'era of ferment' which happens until a new dominant design has emerged from competition between actors (Anderson and Tushman, 1990). The selection of the new dominant design in turn leads to and is supported by the build-up of standards and optimised organisational processes around it (Anderson and Tushman, 1990). Thus, the concept of regimes implies rules, technologies and actor-networks as the main components that can enforce stability or, when they change, create instability of the regime. Therefore, we propose our regime destabilising functions to be linked to changes in rules, technologies and actor networks (drawing on Kern, 2012, and Verbong and Geels, 2007).

In our analytical framework (Table 1), rules are divided into two functions: control policies implying efforts to control the environmental impacts of the existing regime (D1) and significant changes in regime rules referring to structural reforms in legislation and significant new overarching laws that are not necessarily directly or solely targeting environmental impacts (D2). The transition management literature has long argued that 'control policies' (D1), one

not independent but works through strengthening the other six functions", which is why we focus on the other six functions.

[2] The concept of 'dominant design' originated in the literature on technology cycles, in which has been predominantly used in an industry context rather than in the context of (broader) socio-technical regimes. In this literature, technological discontinuities trigger a period of ferment – characterised by 'substantial rivalry between alternative technological regimes' – that ends in the emergence of a new dominant design; one example being the internal combustion engine used in powering automobiles. The dominant design is argued to lead a period of incremental improvements and incorporate a technological regime that is more orderly. (Anderson and Tushman, 1990). We connect to these concepts here because, they not only build on the idea of creative destruction, but according to Anderson and Tushman (1990, p. 606) the dominant design "technology could be examined at several levels of analysis".

example being the EU Emissions Trading Scheme, are required to put pressure on the regime. For example, internalising the environmental costs of carbon emissions is claimed to be crucial in creating an 'extended level playing field' for niches and incumbent technologies to compete on fair terms (van den Bergh et al., 2006). Kemp and Rotmans (2004) argue that without such policies the fostering of niche innovations will not lead to transitions. There is indeed much evidence to suggest that both niche support policies and policies to internalise externalities are required and that neither of them is a good substitute for the other, see e.g. Newell (2010) and Popp (2006). However, a relatively high carbon tax would to some extent enable lower deployment subsidies to be effective than would otherwise be the case.

In addition to internalising externalities, it has been suggested that transitions require significant changes to regime rules (D2) in ways favourable to niches, because existing rules normally hinder path-breaking innovations (Smith and Raven, 2012). Turnheim and Geels (2012, 2013) argue that, as part of regime destabilisation, the 'weakening reproduction of core regime elements' is seen as necessary to create 'windows of opportunity' for the upscaling of niche innovations. Particularly, radical policy reforms, where policies substantially change economic frame conditions, may accelerate destabilisation (Turnheim and Geels, 2012). Such examples are the UK electricity market reform which gave priority to low carbon electricity generation options (Kern et al., 2014) and the coal market reforms in the 1980s and 1990s showing that "industries can be *deliberately* destabilised" (Turnheim and Geels, 2012, p. 48).

In terms of changes in technologies, creative destruction through disruptive innovation involves processes by which resources, skills and knowledge held by incumbents become obsolete; in an industrial context, implying that, for example, the value of existing expertise and other factors of production reduce significantly (Abernathy and Clark, 1985). This is a rare event (Anderson and Tushman, 1990) as support for incumbent technologies is often institutionalised within the rules of the regimes making it difficult for innovations to break through (Smith and Raven, 2012; Turnheim and Geels, 2012). Historical evidence shows that destabilisation normally entails weakening flows of resources into the reproduction of regime elements including core technologies (Turnheim and Geels, 2013). For example fossil fuel technologies are heavily subsidised and "their removal would greatly contribute to their destabilisation" (Turnheim and Geels, 2012, p. 48). Thus, policy mixes for destabilisation may involve weakening flows of human and financial resources to established technologies and practices in the form of withdrawn subsidies or the shut-down of education programmes for engineers focused on particular technologies (D3). For example, in Germany, as part of the phase-out of nuclear power, federal research funding has been withdrawn from nuclear fission research.

A core process within transitions is the entry of new players challenging established regime practices. People able to think 'outside the box' can make important contributions to radical innovation (Bower and Christensen, 1995) and policy processes (Christopoulos and Ingold, 2015). The interests that these 'outsiders' have in existing systems tend to differ from the vested interests of incumbent actors, who carry more 'sunk costs' and are consequently more tied to perpetuating the existing way of doing things. Close relationships between the government and incumbent regime actors are often seen as a major source of lock-in (Unruh, 2000; Walker, 2000). New entrants are more likely to develop radical innovations which, if successful, can disrupt and displace the mainstream way of doing things (e.g. Christensen, 1997). Destabilisation at the level of actor-networks may therefore involve the replacement of incumbents with new entrants or the reorientation of incumbents to new regimes (Turnheim and Geels, 2012, p. 35). Deliberately breaking up established actor-network structures or developing different fora to bypass traditional policy networks is one of the strategies recommended by transition management scholars (e.g. Rotmans et al., 2001). From this we deduct that previously dominant governance organisations or networks may be dismantled, replaced with new networks, merged or otherwise altered, decreasing the legitimacy of and commitment to the old regime (D4). An example is the Dutch energy transition programme which by setting up transition platforms explicitly tried to bypass 'normal' policy making processes (Kern and Smith, 2008). Alternatively, the setting up of systemic intermediaries (Kivimaa, 2014) could be regarded as an action aiming to change social networks.

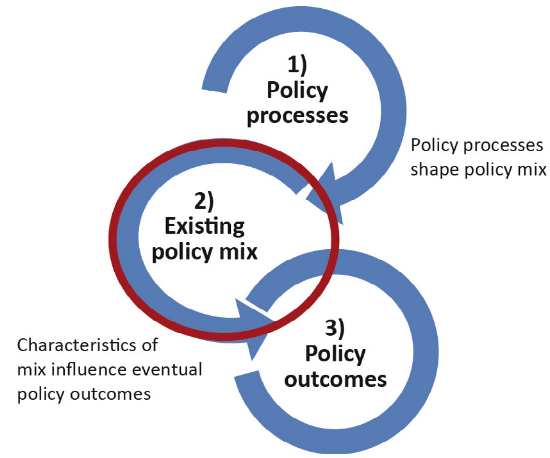

Fig. 1. Focus of analysis.

Overall, the proposed framework seeks to capture what we see as two sides of the same coin: the creation and development of innovations (C-functions) and the destruction of incumbent regimes (D-functions). This analytical framework will be used to empirically map policy instruments to assess whether existing policy mixes have the potential to drive sustainability transitions. The logic is to ascribe each instrument to contributing to one or more of these 'creative destruction' processes to reveal whether or not the existing policy mix addresses the stipulated functions (C1–7 and D1–4).

There is a close relationship between policy processes (including their politics, the institutional contexts in which they are embedded, etc.) and the resulting policy mixes, and their outcomes (Fig. 1). The policy studies literature has much to say about the former (1) and innovation economists have spent much time analysing the latter (3). The focus of our analysis is on the overall characteristics of the policy mix (2). Policy design scholars argue that while it is important to evaluate ex-post the impacts of policy instruments, we can also assess ex-ante the likely outcome of policy mixes by focussing on design criteria for effective policy mixes (Howlett and Rayner, 2007, 2013). Howlett and Rayner (2013, p. 171) suggest that policy mixes, if designed appropriately, can be expected "to have a higher probability of delivering a specific outcome than some other configuration". Coherence is often stipulated as one such design criteria. Some studies have empirically looked at the coherence of policy mixes for sustainability transitions (Kern and Howlett, 2009; Huttunen et al., 2014). Building on this literature and the work on transitions more widely, we suggest that policy mixes aimed at stimulating transitions, in addition to general criteria such as coherence, need to include elements of 'creative destruction' (Table 1) to have better chances to succeed. Our framework is therefore hoped to provide ex ante guidance to policy makers on more effective policy mixes for achieving transitions.

3.2. Methodology

The empirical illustration of the utility of the framework focuses on national-level policies including national implementation of EU legislation. Even though local or regional initiatives also influence transition processes (e.g. Hodson and Marvin, 2010, 2012), they are beyond the scope of this paper.[3] Our analysis is limited to three regimes – mobility, electricity and heating of buildings – which cut across policy domains such as innovation, energy, fiscal and transport policy in two different countries: Finland and the UK. We look for mixes of policies supporting transition processes and, thus, define policy mixes, extending from Borrás and Edquist (2013) as the specific combinations of policy instruments which interact explicitly or implicitly in fostering (in our illustration, low-energy) innovations and disrupting dominant (high-energy) regimes.[4] We examine instruments influencing innovation related to energy demand reduction and improved energy efficiency; thus, for example renewable energy policies focussing merely on the supply side (e.g. wind power, biofuels) are outside the scope of our analysis.

The research method used is a policy mapping exercise. By using four international data sources of policy measures, to enable the collection of comparable data for both countries, lists of relevant policies potentially influencing low energy transitions were identified in September and October 2013. The following sources were used: The International Energy Agency's reviews of energy policies in the UK (IEA, 2012) and Finland (IEA, 2013) and the IEA policies and measures databases on energy efficiency (http://www.iea.org/policiesandmeasures/), the European Environmental Agency's database on climate change mitigation policies and measures in Europe (www.eea.europa.eu/data-and-maps/pam/), the European Commission's Erawatch research and innovation policy database (http://erawatch.jrc.ec.europa.eu/erawatch/opencms/) and the IEA Sustainable Buildings Centre's Building Energy Efficiency Policies (BEEP) database (www.sustainablebuildingscentre.org/pages/beep).[5] Information on the identified policy instruments was complemented by searches made on both countries' governmental websites to find out the objectives, justifications and main content of the policy instruments, and complement the analyses to identify new organisations and networks. The draft lists of policy instruments were sent to four experts from policy and academia in each country, of which two replied per country, to validate the list and to check possible major omissions. We initially identified 70 instruments in the UK and 58 in Finland and added seven Finnish instruments and three UK instruments through the expert review process.

The identified policy instruments were divided into groups based on their target regime: mobility, heating in buildings and electricity. Many policy instruments contributed across these sectors and were categorised as generic innovation policy or energy and climate policy instruments. The instruments that linked across sectors were also often instruments that did not only deal with energy efficiency but also energy supply – making drawing explicit boundaries between energy efficiency and other energy policy instruments difficult. Subsequently the policy instruments were coded in Excel based on the analytical framework categories. Investigator triangulation was used in that both authors coded independently, after which the results were compared. In case of differing opinions, the final coding was negotiated between the authors to ensure consistency.

The aim of the mapping exercise was to analyse how current policy mixes engage or do not engage with processes argued to be crucial for low energy transitions. Particular consideration was paid to the relative attention these policy mixes placed on creation vs. destruction, the relative coverage of the different regimes in terms of number of instruments, and any important gaps. The purpose here was to look at how existing policy mixes fill in all the functions. While we do demonstrate the number of instruments per function, we want to emphasise that the influence of instruments in each function is more relevant than the number of instruments. Yet a low number of instruments in a given function can be used as an indication of an area were further analysis of influence placed by policies on the function is needed.

3.3. Empirical cases: low-energy transitions policy in Finland and the UK

Empirically, the analysis focuses on low-energy innovations which we define as innovations reducing the demand for energy and/or increasing energy efficiency. Such innovations include more energy efficient technologies, such as LED lighting or new building designs, but they might also include social (e.g. car clubs, teleworking) or organisational (e.g. new business models providing energy services) innovations. Our focus complements the existing literature on energy innovation which mostly deals with energy supply (e.g. Foxon et al., 2005; Klaassen et al., 2005). Practices for energy saving and demand have gained some interest recently (Breukers et al., 2013; Heiskanen et al., 2013), while this is a new topic for innovation policy analysis.

Finland and the UK were chosen as case countries as their recent progress in energy efficiency shows differing trends based on an EU wide survey. While the UK was found to have a clear strategy for improving energy efficiency, policy progress in the last three years was ranked from low to moderate; in turn, Finland was ranked among the top three countries in terms of progress in energy efficiency policy (Energy Efficiency Watch, 2013). The countries also differ in terms of their energy use profiles, the UK having one of the lowest energy use per GDP among the IEA countries (IEA, 2012) while Finland has one of the highest (IEA, 2013). In Finland, industry is the largest energy user with nearly half of the total, while in the UK buildings take up the majority of energy use. Furthermore, the countries differ radically in terms of population size and density. Thus, the two countries provide contrasting settings for testing the conceptual framework. In Section 4, the empirical mapping is briefly presented, first, giving an overview and, then, covering destabilising functions in more detail as this is where we claim the added value of our framework.

4. Low energy policy mixes in Finland and the UK

4.1. The low-energy policy mix in Finland

With one third of the country being located above the Arctic circle and given its energy intensive industry (incl. pulp and paper, chemicals, metals, electronics) Finland has the highest energy use per capita of all IEA countries (IEA, 2013). The industrial sector is the largest energy user (47.5% of total final use), followed by the residential sector (20%), while the commercial and other service sectors accounted for 15.3% in 2011. Transport accounted only for 17.2%; the lowest percentage among IEA member countries. The Finnish building stock is very efficient and makes extensive use of

[3] The existing databases used for the analysis unfortunately only cover national level instruments.

[4] While in terms of empirical illustration, we focus on instrument mixes, we see the usability of our proposed framework also in examining in more detail mixes of policy goals, instruments, and processes and how they in combination influence transitions. However, such a wider analysis is beyond the scope of this paper.

[5] No equivalent database exists for transport policies but the other sources cover many transport-related policies.

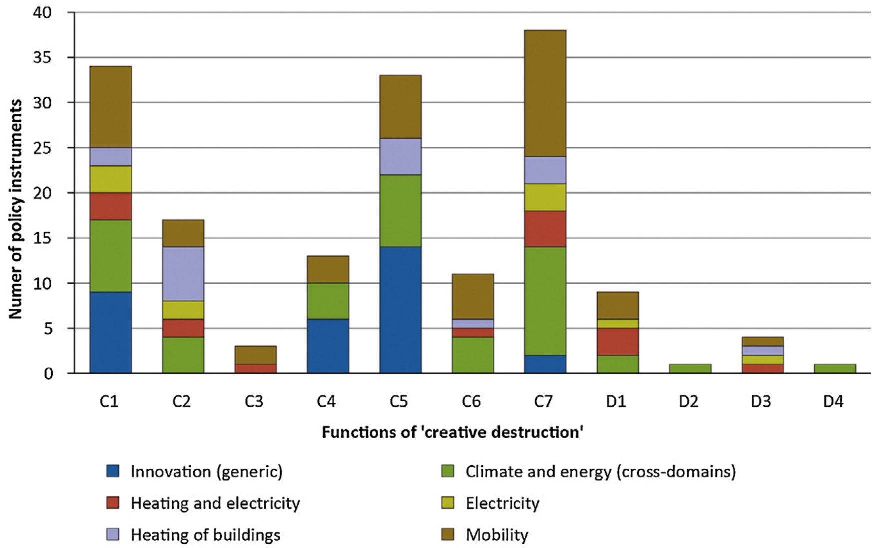

Fig. 2. Finland's 'low energy' policy mix.

district heating, 75% of which is provided by combined heat and power plants.

Our analysis of the Finnish policy mix shows a wide range of instruments targeted at different energy regimes that in combination influence all niche supporting and regime destabilising functions. However, very few instruments address price-performance improvements (C3) and the destabilising functions (Fig. 2). A multitude of policy instruments influencing mobility and the heating of buildings are in force, while electricity use is somewhat less targeted.

A gap in the policy mix exists for transport, heating of buildings and electricity regimes regarding 'entrepreneurial experimentation' (C4), which is left to be addressed by generic innovation and climate and energy policies (such as Finnvera's financial services for start-ups and micro-enterprises and energy efficiency guidelines for public procurement).[6] For example, the energy aid scheme provides subsidies on a discretionary basis on investment projects that "promote energy conservation or improve the efficiency of energy production or use". This policy coupled with electricity tax increases (linked to market formation C2, influence on the direction of search C7, control policies D1) and energy performance requirements for new buildings (contributing to market formation C2, price-performance improvements C3, direction of search C7, and control policies D1) could at the same time destabilise the existing regime, contribute to a transition towards zero energy buildings and create niche-innovations for energy saving solutions in construction. Yet, there is no guarantee that resources in connection to generic innovation support will actually be allocated for the purpose of supporting energy demand reduction or efficiency.

In total we found nine control policies (D1), one significant change in regime rules (D2), four policies representing the removal of support for dominant technologies (D3), and one change in actor-networks (D4). The regime-specific control policies ranged from environmental amendments in tax regimes (for vehicles, transport fuels, electricity, natural gas and heating) to performance standards and regulations for new cars and buildings. Three of the D1 policies concerned mobility, four concerned electricity and heating, and two were more generic climate policies, such as the EU Emissions Trading Scheme. For example, the National Building Code sets requirements for the energy use of Finland's building stock in accordance with the EU Directive on the Energy Performance of Buildings. The 2012 revision pushes Finland's already stringent energy performance requirements up by a further 30%, and now also takes into account the energy source of the building.

We interpreted a recent revision in the Land Use and Building Act, influencing energy use across regimes, as a significant change in regime rules (D2). The revised Act aims to ensure energy efficiency and resource efficiency in the renovation of buildings and to avoid disruptive land use development and increased transportation needs specifically by limiting the construction of retail centres based on private car transportation. Its significance is based on the expansion of support for energy efficiency through the Act and the strengthening of the instruments of the law (for example, by providing mandates to municipalities to make obligations linked to reduced energy use).

Amendment of the fuel tax to be based on the energy content of the fuel and an increased tax level for fossil fuel based heating were considered as removal of support for dominant technologies (D3) as was the EU wide ban on incandescent light bulbs. Fuel tax in general reduces support for high-energy consuming vehicles and practices and, when taking into account the energy content of the fuel, this effect is intensified to support the most efficient fuels. At the same time, the attempts to significantly reduce the tax break for work-based travel, increasing transport energy use, have failed due to political difficulties.

No significant changes in policy networks or key actors (D4) were identified in policy instrument databases but the other sources revealed a potential new destabilising actor in the energy regime. Inspired by a group of distinguished professors publishing a report on the need for new energy policy, an action focused network was established based on open engagement with a variety of actors from associations to a range of small and larger companies. The network aimed to lift energy policy as one of the most important goals for the new government resulting from spring 2015 elections and bring resource use as its focus.

Overall, the Finnish policy mix demonstrates an imbalance between creation and destabilisation policies, not only as numbers of instruments, but also in terms of content, particularly linking to significant changes in regime rules and changes in official policy networks and actors. The large number of policies influencing the low energy field in general may, in turn, create increased likelihood

[6] A previous study on mobility-related policies noted a lack of significant national-level instruments related to 'entrepreneurial experimentation' (C4) and 'market formation' (C2) (Kivimaa and Virkamäki, 2014).

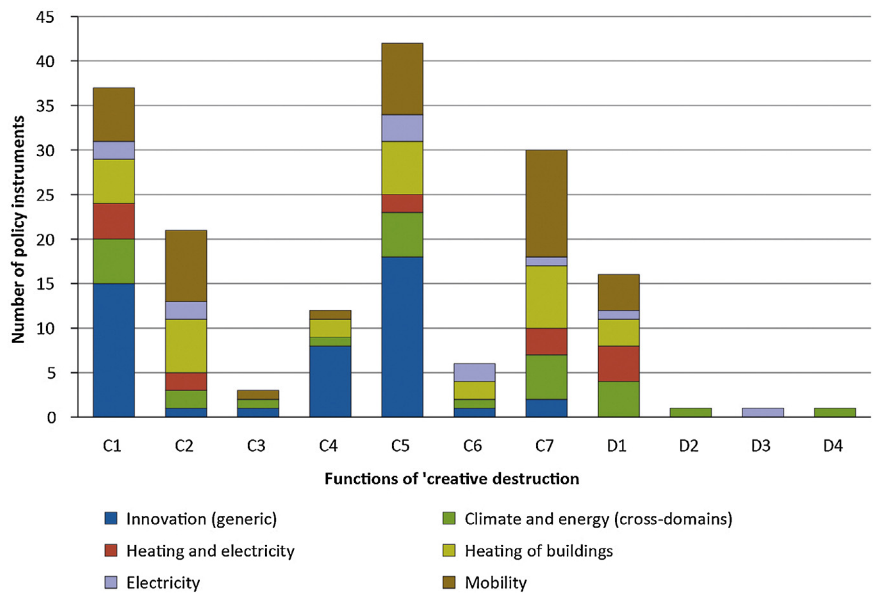

Fig. 3. UK 'low energy' policy mix.

for inconsistencies due to the layering of policies. More attention is needed on how the multiple policies crossing regimes and domains influence transitions.

4.2. The low-energy policy mix in the UK

The largest end-use of energy in the UK occurs in the residential sector, amounting to 32% of total final use, followed by transport with 30%, industry with 25% and commercial and other sectors with 13% in 2010. According to the IEA (2012, p. 13), "[e]nergy use per unit of GDP in the United Kingdom is one of the lowest among the IEA member countries, reflecting both the large share of services and the small share of energy-intensive industry in the economy, but also improvements in energy efficiency".

Our analysis of the UK policy mix shows a wide range of instruments targeted at different energy regimes that in combination influence all niche supporting functions and regime destabilising functions (Fig. 3). However, as in the Finnish case, very few instruments address price-performance improvements (C3) and the destabilising functions (D1–4). A multitude of policy instruments influencing mobility and the heating of buildings are in force, while electricity use on its own is somewhat less targeted. However, several instruments address electricity and heating simultaneously.

The UK has recently introduced several policy instruments influencing energy efficiency and energy demand in the heating of buildings and mobility. Both sectors present fairly comprehensive policy mixes from the perspective of niche support with only legitimising instruments (C6) missing for mobility. However, many of the mobility policies (at least at the national level) focus specifically on automobility (such as car tax reforms, programmes for electric mobility, fuel economy labels, the Low Carbon Vehicle Partnership) rather than alternative mobility systems (cycling, walking, public transport) (see Supplementary data). Many of such initiatives are happening at the city or local level (e.g. congestion charging in London, city bike schemes, car clubs).[7] Less focus in terms of energy efficiency measures has been placed on the electricity sector that is dominated by supply side instruments trying to stimulate the uptake of renewable energy technologies, nuclear and CCS.

As in the Finnish case, a gap in the policy mixes for the heating of buildings and electricity regimes exists regarding 'entrepreneurial experimentation' (C4), which is mainly left to be addressed by generic innovation and climate and energy policies (with the exception of the Carbon Trust which fosters 'entrepreneurial experimentation' (C4) for example through an incubation scheme for low carbon businesses).

Similarly to Finland, few policy instruments were found to contribute to the destabilisation of existing regimes (D1–4). In total, we identified 16 instruments as 'control policies' (D1), one significant change in regime rules (D2), one policy removing support for established technologies (D3) and one new actor (D4). As in Finland, control policies included minimum performance standards for new passenger cars and buildings, changes in taxation (e.g. company car tax reform, fuel duty escalator) and the Emissions Trading Scheme. In addition, the UK had a range of policy instruments and packages – differing from Finland – as further control policies: a requirement of private landlords to make reasonable energy efficiency improvements required by tenants, the Climate Change Levy on energy for lighting, heating and power aimed at encouraging energy efficiency in businesses, the Carbon Price Floor as part of the electricity market reform, and the Government Buying Standards. All these instruments put economic or regulatory pressure on existing regime practices. For example, the Carbon Price Floor, by ensuring a minimum price of carbon, aims to reduce the use of carbon intensive fossil fuels and to address the weakness of the EU Emissions Trading Scheme.

Our UK analysis identified one policy instrument deemed to directly address significant changes in regime rules (D2): the 2008 Climate Change Act. The act aims for a 50% reduction in greenhouse gas emissions from 1990 to 2027 and a reduction of 80% by 2050. According to the Act, a system of "carbon budgets" limits UK emissions over successive five-year periods and sets the trajectory to 2050. Most emphasis has so far been put on change within the electricity regime (e.g. with regard to the roll-out of low carbon generation) but the recent electricity market reform introduces a number of instruments putting pressure on fossil fuel plant operators. The reform mainly deals with energy supply rather than energy use or energy-efficiency but, for example, capacity payments have been introduced to ensure sufficient system flexibility to maintain reliable supplies, and will also involve demand-side response issues.

[7] Expert review comment.

The only instrument we identified as being directly targeted at withdrawing support for a dominant regime technology (D3) was the EU ban of incandescent light bulbs introduced in 2012. The EU ban aimed to increase the energy efficiency of lighting and sent a strong signal to manufacturers and consumers by using the most draconian policy measure available: an outright ban. This is the most extreme form of withdrawing support for a technology which has been dominating domestic lighting practices for more than a century. Potentially such an instrument, in combination with other instruments such as the national products policy (legislation to set minimum energy efficiency standards for products on sale and mandating energy efficiency labelling of appliances), also has a signalling effect for manufacturers of other highly-energy inefficient products.

The Climate Change Committee (CCC) set up to oversee the execution of the Climate Change Act represents a change in key actors (D4). The CCC independently advises the governments on the carbon budgets required to meet the long term targets enshrined in the act, advises on policy actions to reduce emissions, and measures progress against the targets. As such the CCC has become an influential body within UK energy and climate policy and there have been several instances of conflicts (e.g. around the fourth carbon budget) between the government and the advice of the CCC but so far the CCC has prevailed.

Overall, as in the Finnish case, there is an imbalance between creative and destructive policies, but there is a slightly larger focus in the UK on destabilising policies than in Finland (a wider range of control policies being used). Especially, the Carbon Price Floor is principally able to contribute to the destabilisation of high energy regimes, but much depends on its future setting (e.g. planned increases were recently frozen). Significant policy attention has been devoted to low energy innovation in the UK, and several new policy instruments were added to the existing mix, which suggests an increased likelihood for inconsistencies because of layering of policies. The government is aware of this challenge and has commissioned a report (*Opportunities for integrating demand side energy policies*) which concluded that there is a wide range of government programmes supporting energy efficiency and distributed energy solutions but that a lack of integration could cause policies to compete or undermine each other's effectiveness.

5. Discussion

The empirical analysis showed that the framework developed in this paper – combining seven niche support (creative) functions with four regime destabilising (destruction) functions – can reveal interesting lessons about policy mixes for sustainability transitions. We suggest that policy mixes which cover both dimensions of 'creative destruction' are more likely to achieve transitions. Interestingly, both countries show largely similar policy mix profiles (demonstrated in Figs. 2 and 3), while the mix of UK policies for 'destruction' appears more innovative and extensive.

As expected we found fewer policy instruments directly tackling regime destabilisation (D-functions) than niche support (C-functions). Relatively many control policies (D1) were found in both countries that simultaneously also influenced market formation (C2) and/or the direction of search (C7). Some UK D1 instruments also influenced knowledge creation and diffusion (C1) and resource mobilisation (C5).

We found two examples of significant changes in regime rules (D2): the revision of the Land Use and Building Act in Finland and the Climate Change Act in the UK. The rarity of this function can probably be explained by the political hostility towards structural change and the difficulties to politically sustain it (Lockwood, 2013).

We identified only a few changes in support for dominant technologies (D3) directly applicable to the reduction of energy demand or improvement of energy efficiency, such as the EU-wide ban on incandescent light bulbs and the amendment of transport fuel taxation in Finland. However, indirectly, the removal of support for fossil fuels is a measure destabilising the high-energy regime and has clear implications: reduced support for fossil fuel exploration and production may increase energy prices and, thereby, increase incentives for low energy innovations. In the UK, several such measures have been taken, for example, the removal of subsidies for coal mine operating costs, in 2002, and for maintaining access to already exploited coal reserves in 2008 (IEA, 2012, p. 93). What the examples of selected destabilising policies may also indicate is that not so many destabilising policies may be necessary, as long as they exist in a form able to disrupt the regime.

Destabilisation policies are politically difficult. That we find few examples of such policies is therefore not surprising. In a general sense the development of energy policy mixes in both countries probably represent what Howlett and Rayner (2007) would classify as *layering*, while destabilising policies–particularly those addressing reduced support for dominant regime technologies, replacement of key actors, or significant changes in rules would require a *replacement* (Kern and Howlett, 2009) approach. Jänicke and Jacob (2005) have argued that necessary structural change from an environmental perspective, such as the phasing out of nuclear energy or the use of lignite coal, requires huge political endeavour and is therefore possible only in exceptional circumstances. Also Meadowcroft (2005, 2011) has made a similar point. Moreover, designing policies attempting to undermine existing regimes is challenging, because they present a contradictory ideology to that of traditional innovation policies, often aimed to contribute to economic growth (e.g. Alkemade et al., 2011), and because they are likely to require significant backing of major political parties (e.g. Strunz, 2014).

However, there are a number of arguments policymakers can use to justify destructive policies: one is that destabilising existing regimes is one way of achieving more effective competition (in the sense of 'levelling the playing field'). A second justification might be that such policies are required to free Keynes's 'animal spirits' necessary for radical entrepreneurship and its effects in terms of 'creative destruction'. Yet even in the event of political backing for restructuring policy mixes in a given domain, such as energy or innovation, the creation of new policy designs requires a sophisticated analysis of policy dynamics and instrument choice (Howlett and Rayner, 2007), while still facing the risk of sub-optimal policy mixes (Kern and Howlett, 2009) particularly when confronted with policy instruments designed for completely different purposes.

Our empirics also point to connections within policy mixes. Whereas the discussion on the synergies and contradictions (cf. Nilsson et al., 2012; Rogge and Reichardt, 2013) or cumulative causation (cf. Suurs and Hekkert, 2009) between the elements of this framework cannot be addressed here in detail, some observations on the links between creative and destructive policies can be made. Control policies (D1) have a clear dual function in destabilising the current regime, often by controlling the environmental impacts, while at the same time supporting niche development through creating markets for niche innovations (C2), in effect contributing to multiple "motors" (see Section 2.2) at the same time. The EU Directives on Emissions Trading or the Energy Performance Standards for buildings are good examples.

Less directly, knowledge creation, development and diffusion (C1) and resource mobilisation (C5) might be linked to the removal of support for established technologies (D3) in that re-directing research funding, education and science to certain areas simultaneously may promote niches and withdraw support from established technologies. This means that a mix of policy instruments could both contribute to the Science and Technology Push (STP) motor of a new TIS and diminish the STP motor of the dominant regime simultaneously. In that sense it seems useful to expand the concept of 'motors of innovation' to 'motors of creative destruction'. We argue that while the cumulative build-up of various innovation system functions (here covered through the niche support functions) is necessary, on its own it is insufficient to drive significant sustainability transitions, especially given the urgency of the required transitions. Therefore, the cumulative effects and dynamics of both niche support and regime destruction processes should be at the centre of attention. Further analysis of these links – particularly those linking significant changes in regime rules (D2) and changes in networks and replacement of key actors (D4) with impacts on niche support functions (C1–7) – would need more detailed case studies with a more limited scope of policies than analysed in this paper.

Our empirical analysis also points to a need for further conceptual and methodological developments. The placing of instruments into functions was sometimes difficult and more specific indicators for each function are needed – particularly on how to interpret the functions 'legitimation' and 'price-performance improvements'. This further definition of functions is necessary to analyse the effects of policy mixes but is likely to require further empirical studies on destabilising policies and how their effects unfold to provide insights into the actual content and nature of destabilising functions and the resulting new governance arrangements.

Often policy instruments can be interpreted to be contributing to specific functions or not depending on how narrow or wide the interpretation of the function is. For example, in terms of resource mobilisation (C5) a policy instrument can directly provide resources (e.g. by setting up a public fund for R&D on energy efficiency) or indirectly stimulate the mobilisation of resources by other actors (e.g. by setting vehicle emission standards leading to stronger R&D efforts by car manufacturers or by establishing a prestigious energy efficiency award which might stimulate investment by private actors). This is not only a problem of classification but also influences the potential effect of policies. Interpreting functions in a narrow way enables better identification of potential policy gaps to be analysed in more detail when observed.

6. Conclusions

Our aim was to broaden the discussion within the technology and innovation studies literature about the importance of policy mixes. We argued that policy mixes are particularly important and challenging, if policy is aimed not just at the creation or diffusion of innovations but at transforming entire socio-technical systems towards sustainability. Drawing on the existing policy mix and sustainability transitions literatures, the contribution of this paper was to explicitly conceptualise policy mixes for sustainability transitions. Our key argument was that policy mixes for sustainability transitions should incorporate instruments addressing two dimensions: those aimed at creating niche-innovations and building effective innovation systems around them, and those aimed at destabilising currently dominant regimes creating openings for a speedier take-off and sustained growth of niche innovations to replace incumbent (high energy) technologies. We therefore propose to expand to concept of 'motors of innovation' to 'motors of creative destruction' to incorporate attention to the required destabilisation processes of incumbent regimes.

We specifically built on the Technological Innovation System (TIS) functions and Strategic Niche Management for developing niche support functions, while for the destabilisation functions we utilised Schumpeter's seminal concept of 'creative destruction', the concept of regime destabilisation by Turnheim and Geels (2012, 2013) and some ideas of transition management (Rotmans et al., 2001). By initiating a discussion on policies destabilising current regimes, we wish to facilitate further analyses of policy mixes going beyond stimulating individual technologies as in much of the existing TIS literature.

We argue that the conceptual framework and the analysis presented in this paper are a first step towards examining policy mixes from the perspective of sustainability transitions. Empirically, we have provided an overview of which processes are targeted by existing policy mixes in the UK and Finnish low-energy transitions and have identified some important gaps, particularly the lack of destabilising policies generally as well as sector- and technology specific policies addressing price-performance improvements and entrepreneurial experimentation. Given these gaps in the current policy mix designs, more attention should be placed by policymakers on whether the current policy mixes are sufficient to achieve the ambitious long-term targets for energy efficiency and energy demand reduction. Conceptually, we have developed an extension of the TIS functions approach, by adding four regime destabilisation functions (D1: control policies, D2: significant changes in regime rules, D3: reduction in support for dominant technologies, and D4: changes in social networks and replacement of key actors), and tested the framework against two case studies which emphasised the need for further conceptual and methodological refinements.

Admittedly, the approach presented in the paper is a very proxy way of analysing policy mixes and necessarily quite crude. One shortcoming of the kind of analysis conducted here is that, while we see a variety of instruments aimed at energy demand reduction, little can be said about their actual effectiveness. A more detailed analysis of a limited set of instruments, their development over time and their impact on the strategies of target groups should be conducted to build on and complement our overview. In more detailed analyses, interviews with target group actors could shed light on how actors interpret the signals they receive from different policy instruments (cf. Huttunen et al., 2014) and how this shapes their strategies. Alternatively, econometric techniques could be used to assess the combined impact of policy mixes. While these kinds of studies have been carried out, so far they have not extended to examining the impacts from the perspective of creative destruction for sustainability transitions.

We argue that the type of analysis carried out in this paper is also of use for policymakers. Importantly, it shows that the mix of generic innovation policies and targeted sectoral (and technology-specific) policies is important to create more complete policy mixes from the perspective of transitions – following Weber and Rohracher's (2012) call for a combination of 'structural innovation policies' and 'transformation-oriented innovation policies'. Applying the concept of 'creative destruction' in the context of public policy will hopefully help to expand innovation policy debates to go beyond policy mixes consisting of technology push and demand pull instruments, and to consider a wider range of policy instruments which may contribute to both the creation and development of niches as well the destabilisation of existing regimes.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.respol.2015.09.008.

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