2

Conceptualising Socio-Technical System Reconfiguration

This chapter presents our conceptual elaborations, which, together with the Multi-Level Perspective (MLP) described in Section 1.2, will guide the empirical analyses of system reconfigurations in Chapters 4, 5, and 6. It consists of two complementary parts. The first part, which stays close to the existing literature, conceptualises socio-technical transitions by following the innovation journey of niche-innovations. It builds on the MLP but elaborates four different phases. For each phase, we describe the main processes and mechanisms with regard to three dimensions: 1) techno-economic developments, 2) actors and social networks, and 3) policies and governance. The systematic conceptual discussion of these three dimensions over time has not been done before and thus constitutes a contribution to the socio-technical transitions literature. In particular, it more systematically introduces techno-economic developments in the MLP (Cherp et al., 2018).

The second part, which aims to make more substantial contributions to the literature, conceptualises system reconfiguration by describing change processes in the *existing* socio-technical system. Focusing on techno-economic and material components, we build on McMeekin et al. (2019) in distinguishing four change processes: 1) 'modular incrementalism', which incrementally improves existing components, 2) 'modular substitution', which involves replacement of particular components, 3) 'architectural stretching', which extends or elaborates linkages between existing components, and 4) 'architectural reshaping', which involves component replacement and changing linkages between components. Focusing on actors and social networks, we describe reorientation processes of incumbent actors, who can shift their attention, support, or resources from the existing system to emerging niche-innovations. Focusing on policies, we describe how existing policy and governance frameworks can be adjusted to accommodate new issues such as climate change.

We propose and will empirically demonstrate that a comprehensive analysis of low-carbon system reconfiguration should use both analytical lenses, which trace

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

the emergence of low-carbon niche-innovations as well as reorientation processes in existing systems.

2.1 The Emergence and Diffusion of Radical Innovation in Socio-Technical Transitions

Radical innovations, which deviate substantially from the existing system on one or more dimensions, are important in low-carbon system reconfiguration, because incremental improvements will not be enough to deliver the large reductions in GHG emissions needed to address climate change. It therefore makes sense to analyse the innovation journey of niche-innovations with reference to ideal-typical phases, although this heuristic also has limitations, as we will discuss further. As indicated in Figure 1.4, the existing socio-technical transitions literature often divides long-term transitions into four phases, which are characterised by different processes and mechanisms. Combining insights from the sociology of innovation, evolutionary economics, and innovation management, we describe the main processes for each phase, organised along three analytical dimensions (techno-economic, actors, institutions).

2.1.1 First Phase: Experimentation in Protected Spaces

In the first phase, radical innovations emerge in small niches, often outside or on the fringe of the existing system (Schot and Geels, 2008). Through subsidised R&D or pilot projects, niches provide 'protected spaces' that shelter radical innovations from mainstream market selection pressure and nurture learning and development processes (Smith and Raven, 2012).

Techno-Economic: The technological (or social or business model) innovation is just emerging in this phase, and there are many uncertainties about technological characteristics, user preferences, policy, infrastructure requirements, and cultural meanings (Kemp et al., 1998). Multiple design variations may co-exist, which exacerbates uncertainties. Performance tends to be low and costs high, so the innovations struggle to survive economically, and often depend on financial support from policymakers (e.g., subsidies for R&D or demonstration projects) or specialised investors (e.g., venture capital, business angels). The fluidity and divergence of niche-innovations is represented with small diverging arrows in the bottom-left corner of Figure 1.4. Markets may not readily exist for radical innovations. There may be uncertainty about who the users are, what their preferences are, and what the final functionality of the new technology will be. Pervasive uncertainties complicate the use of cost-benefit calculations in this

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

phase. In fact, over-reliance on financial assessment tools may act as 'innovation killers' in this phase (Christensen et al., 2008).

Policies and Governance: There are no stable design rules, guidelines, standards, policies, or governance structures in this early phase, given that radical innovations do not initially 'fit' with prevailing regulatory and selection environments. If there is policy support, this tends to be small and relatively uncommitting, often in the form of seed money for demonstration projects or subsidies for R&D.

Actors and Social Networks: Radical innovations are often pioneered by inventors, entrepreneurs, start-ups, activists, or other relative outsiders (Van De Poel, 2000), although incumbent firms can also develop novelties in their R&D laboratories. The social networks of niche-innovators and their wider support coalitions are small and unstable in this phase and characterised by high degrees of entry and exit. The Strategic Niche Management (SNM) literature (Kemp et al., 1998; Schot and Geels, 2008) distinguishes three actor-related processes that drive the emergence of niche-innovations: 1) learning processes through experiments or on-the-ground demonstration projects, aimed at reducing uncertainties and gradually improving the innovation, 2) the enlargement of *social networks* and the enrolment of more actors to expand the social and resource base of niche-innovations, 3) the articulation of *expectations* or *visions* to provide direction to the innovation activities and attract attention and funding from external actors (Borup et al., 2006). Champions of radical innovations may over-inflate their promises (of the innovation's performance, market potential, or transformative effects), which can lead to hype-disappointment cycles (van Lente et al., 2013) if the initial 'buzz', media-attention or investment influx are followed by setbacks, problems, and delays.

Network building, learning processes, and the articulation of credible and appealing visions may take a long time: 'There may be long periods when only a few pioneers advocate change without much attention, before a tipping point comes which leads to a swarm of competing alternatives, that is then followed by a period of winnowing out, and then the consolidation of a much smaller number of models that turn out to be viable' (NESTA, 2013). Radical innovations are risky, and many new entrants, innovations, and promises fail to survive the lengthy first phase, because of a lack of financial and organisational means (Olleros, 1986).

In the first phase, niche-innovations do not (yet) form a threat to the existing system, which is entrenched in many ways (institutionally, organisationally, economically, culturally). The existing system is not inert but changes incrementally due to small improvements in existing technologies, policy instruments, markets, and cultural meanings, which produce predictable trajectories (represented as stable lines in Figure 1.4).

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

2.1.2 Second Phase: Stabilisation in Small Market Niches

Techno-Economic: In the second phase, radical innovations break out of protected spaces and establish a foothold in one or more market niches. This provides a more reliable flow of resources, which stabilises the innovation and makes it more attractive for other actors. Learning processes focus on improving functionality and performance rather than cost: 'Performance dominates cost in initial market niches' (Wilson and Grubler, 2011: 168).

Policies and Governance: Learning processes also gradually lead to the stabilisation of a dominant design (Anderson and Tushman, 1990), which becomes institutionalised in design guidelines, product specifications, best practice formulations, and standards. The innovation thus develops a trajectory of its own because of the stabilisation of rules and social networks (represented in Figure 1.4 with converging arrows in the second phase). Policy support often becomes stronger in this phase and may take the form of investment subsidies for firms, purchase subsidies for consumers, public procurement, or feed-in-tariffs, which help to create and expand market niches.

Actors and Social Networks: Social networks and alliances become bigger in the second phase as a dedicated community (of firms, engineers, policymakers, users) emerges. The participation of more actors (including powerful incumbents) increases the legitimacy of the innovation and brings more resources into niches (Schot and Geels, 2008). Social interactions, learning, and articulation processes begin to reduce uncertainties, and future visions become more precise and more broadly accepted. Dedicated professional groups (e.g., engineering communities, branch organisations) emerge, which help to codify the new body of knowledge (Geels and Deuten, 2006) and lobby for more policy support. Technological stabilisation and emerging economic opportunities increase the willingness of firms, policymakers, and financial actors to invest. The involvement of more mainstream actors may reduce the radical scope and visions compared to the intentions of initial innovators, which can be seen as the 'price of success' (Smith et al., 2014).

Innovation may also happen on the user side, as people 'domesticate' radical innovations and transform them from unfamiliar things to familiar objects embedded in the routines and practices of everyday life (Lie and Sørensen, 1996). The articulation of positive cultural visions may help to legitimate innovations and attract further support.

Innovations may, however, also be opposed by social groups who experience negative side-effects or by citizens who feel insufficiently consulted in decision-making. Such opposition may result in controversy and social acceptance problems that can hinder further progression of the innovation, as happened with nuclear

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

energy, genetically modified food, and onshore wind turbines in some countries (Batel, 2018; Geels et al., 2007).

Innovations may remain stuck in market niches for a long time, especially when they face a mismatch with the existing system (e.g., infrastructure, user preferences, institutional barriers). Niche advocates may try to alter wider contexts through political lobbying and institutional entrepreneurship (Smith and Raven, 2012), but incumbent regime actors may actively resist these changes (Geels, 2014).

2.1.3 Third Phase: Diffusion and Struggles against the Existing System

Techno-Economic: In the third phase, the innovation diffuses into mainstream markets, where it competes head-on with the existing technology in terms of techno-economic performance and wider socio-technical system in terms of 'institutional fit'. Diffusion often follows a pattern of 'niche-accumulation' (Geels, 2002), with an innovation emerging in a technological niche, then moving to a small market niche or application domain, and subsequently into larger mainstream markets (Figure 2.1).

Important techno-economic drivers of diffusion are cost reductions and performance improvements, which Arthur (1988: 591) related to five positive feedback mechanisms of increasing returns to adoption: 1) scale economies in production, which allow the price per unit to go down, 2) learning-by-using: the more a technology is used, the more is learned about it, the more it is improved; 3) technological interrelatedness: the more a technology is used, the more complementary technologies are developed; 4) network externalities: the more a technology is used by other users, the greater its usefulness and performance; 5) informational increasing returns: the more a technology is used, the more information becomes available and is shared among users.

The entry in mainstream markets leads to economic competition between new and existing technologies, the outcome of which depends not only on price/performance characteristics but also on the institutions that shape markets and economic frame conditions.

Policies and Governance: Diffusion into mainstream markets is often accompanied by adjustments in regulations and policies so that these become more supportive of radical innovations (EEA, 2019a). New product regulations

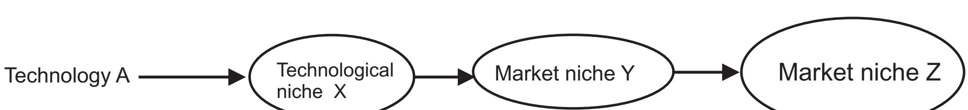

Figure 2.1 Diffusion as a process of niche-accumulation (adapted from Levinthal (1998: 243))

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

(e.g., energy efficiency standards for new cars, appliances, or houses) and performance regulations (such as renewable energy obligations for utilities or electric vehicle sales targets for automakers) can drive company engagement. Capital grants or interest-free loans can also stimulate investments and uptake by firms. And purchase subsidies and information campaigns may advance user adoption of innovations (Brand et al., 2013). These policy instruments are often embedded in and supported by new policy goals, visions, and strategies.

Actors and Social Networks: The number of actors increases rapidly in the diffusion phase due to interactions and positive feedbacks (Kanger et al., 2019; Mylan et al., 2019) such as the following: a) decreasing costs stimulate adoption by more users, which increases visibility and markets, b) growing markets and improving technologies attract more firms, which may lead to 'swarming effects' (Schumpeter, 1927) that increase investments and industry size, c) increasing investments further improve technologies and lower costs, while increasing industry size enhances lobbying power, which may result in more favourable policies that stimulate adoption or company investment, d) positive user experiences and the emergence of new industries and jobs may validate positive cultural discourses, which can alter user preferences and legitimate further policy support (Roberts and Geels, 2018).

To protect their vested interests, incumbent actors may try to resist or delay the transition. Widespread diffusion is therefore often characterised by highly visible struggles and conflicts between actors associated with niche-innovations and existing systems. On the business dimension, there may be struggles between new entrants and incumbents, which may follow different patterns: 1) new entrants may outcompete and replace existing firms (Christensen, 1997); 2) incumbent firms may defend the existing system by improving the existing technology, hindering the new innovation (through pricing strategies or political tactics), or buying up the new firms (to eliminate the risk and/or acquire new capabilities), 3) incumbent firms may diversify and reorient themselves towards new technologies. Car manufacturers, for instance, can diversify towards electric vehicles (Penna and Geels, 2015), while electric utilities can diversify towards renewables (Geels et al., 2016b). This means that incumbent actors *can* play constructive roles in transitions, even when they initially tend to resist.

On the political dimension, there may be conflicts and power struggles about the *settings* of policy instruments (e.g., adjustments in subsidies, taxes, and regulations) and the *kinds* of instruments (e.g., market-based, regulatory, informational). Political struggles are also about which problems appear on agendas, how they are framed, and what degree of urgency is attached to them (Kern, 2011). These struggles involve traditional policy actors (e.g., bureaucrats, Ministers, advisory committees, political parties, Parliament) but also wider

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

interest groups, which often have differential degrees of access to policy networks (Lockwood et al., 2017). Successful transitions are deeply political processes, because they usually require major changes in policy instruments and in market metrics or measurement tools (Meadowcroft, 2009). Incumbent actors tend to resist such changes, whereas niche-actors push for them. Policy change therefore often requires changes in power relations, for example, strengthening of change coalitions and weakening of incumbent networks.

Transitions also involve cultural and discursive struggles about the framing of problems and solutions (Geels and Verhees, 2011). It matters, for instance, if the problem of climate change is framed as a 'market failure' (which is likely to lead to market instruments such as a carbon pricing) or as a 'planetary boundary' (which may lead to stronger policies with greater urgency). It also matters how particular solutions are framed and given meaning. For instance, are wind turbines primarily seen as renewable energy producers or as ugly artefacts that kills birds? Are nuclear power plants seen as low-carbon energy producers or as existential threats? Different social groups may have different views and interpretations, which often leads to contestation. These cultural dimensions are also important with regard to social acceptance of solutions and the legitimacy of policy efforts (Markard et al., 2016).

There is no guarantee that niche-advocates inevitably win the various struggles. Niche-innovations may fail to build up sufficient endogenous momentum or suffer setbacks. Incumbent actors may successfully counter-mobilise and thwart or stall niche-innovations. Or the existing system remains deeply locked-in and proves difficult to dislodge.

The MLP therefore suggests that broad diffusion often involves not only *endogenous* drivers of niche-innovations but also *external* landscape developments that create pressure on the existing system, which may lead to tensions and cracks (represented by diverging arrows in Figure 1.4) that, in turn, may create windows of opportunity for niche-innovations. Problems and tensions that may destabilise existing systems include the following (Turnheim and Geels, 2012): a) performance problems that cannot be met with the available technology, b) changes in markets and mainstream user preferences, c) changing cultural discourses that delegitimise existing technologies (Roberts, 2017), d) changes in policy agendas that lead to stricter regulations, e) competition and strategic games that lead incumbent firms to diversify away from existing technologies and towards niche-innovations (Penna and Geels, 2015).

2.1.4 Fourth Phase: Reconfiguration

Techno-Economic: In the fourth phase, new technologies replace existing ones, which thus decline. This replacement is accompanied by further system

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

reconfiguration, including the creation and expansion of new infrastructures and industrial supply chains, which create forward and backward economic linkages (Hughes, 1994). The post-war establishment of the auto-mobile system, for instance, involved not only an expanding car industry but also stronger linkages with rubber, steel, and glass industries as well as roadbuilding, oil, and servicing industries.

Policies and Governance: The new system becomes anchored in safety regulations, (technological) performance requirements, tax and subsidy rules, and professional standards. New government departments and regulatory agencies may be created to oversee and inspect the system. And new teaching curricula may be developed to train new staff. New policies may be needed to mitigate negative unintended consequences that may be generated by the expanding system. Expanding automobility, for instance, generated more traffic accidents and air pollution, which gave rise to new safety and environmental regulations.

Actors and Social Networks: Social networks gradually expand and stabilise in relation to the new system. The majority of users switch to new technologies and social practices, which stabilises new habits of use and views of normality (Shove, 2003). Successful firms expand their factories, market shares, and supply chains, while 'old' firms decline and shrink. The 'losers' in transitions (e.g., firms, employees, regions) may need to be helped or compensated to mitigate disruptive effects and limit potential resistance (Mayer, 2018; Vögele et al., 2018).

2.1.5 Limitations and Directions for Elaboration

This 'innovation journey' approach is widely used in socio-technical transitions research, especially for analyses that focus on the emergence of disruptive niche-innovations such as solar-PV (Smith et al., 2013), wind turbines (Jolly et al., 2016), electric vehicles (Dijk et al., 2016; Mazur et al., 2018; Sovacool, 2017; Sprei, 2018), community energy (Tom Hargreaves et al., 2013), hydrogen and fuel cell vehicles (Upham et al., 2018). Despite its usefulness it also has several limitations for understanding system transitions, as critics have pointed out.

One limitation is that this approach has a bottom-up bias, representing a 'point source' approach to transitions (Geels, 2018a), which see emerging innovations as the driving force. Berkhout et al. (2004: 62) also criticised this approach for being 'unilinear in that they tend unduly to emphasise processes of regime change which begin within niches and work up'. To address this limitation, and because of our interest in whole system transition, this book shifts the analytical focus towards *existing socio-technical systems*, which we conceptualise as both locked-in and dynamically evolving, both through endogenous processes and pressures from niche-innovations.

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

Another limitation is that the ‘innovation journey’ approach tends to focus on singular radical niche-innovations that emerge and overthrow the existing system. This approach is clearly too simple for understanding low-carbon system transitions, since there are multiple niche-innovations in electricity, heat, and mobility systems. We will therefore build on research that has investigated *multiple* niche-innovations (Dijk et al., 2013; Markard and Hoffmann, 2016; Marletto, 2014; Raven, 2007; Sandén and Hillman, 2011; Verbong et al., 2008) and how these may compete, complement, or build on each other.

A third limitation is that the ‘innovation journey’ approach and the standard MLP representation (also in Figure 1.4) assume that niche-innovations struggle against a *single* existing system, which has been criticised as too limited (Andersen et al., 2020; Rosenbloom, 2020). Some research has tried to address this limitation by investigating interactions between *multiple* systems in transitions (Geels, 2007a; Konrad et al., 2008; Marletto, 2014; Papachristos et al., 2013; Raven and Verbong, 2007). We will build on this research in our investigation of whole electricity systems (which we divided into generation, grid, and consumption sub-systems), passenger mobility (for which we distinguish auto-mobility, train, bus, and cycling systems), and heat (which we relate to heating and buildings systems).

A fourth limitation is that the focus on radical niche-innovations may lead transition scholars to underestimate the potential of incremental change in reducing GHG emissions: ‘Preoccupation with disruptiveness [. . .] risks marginalizing and overlooking [. . .] mundane, incremental and continuity-based innovation, and possibilities for adapting existing systems’ (Winskel, 2018: 235). An exclusive focus on radical niche-innovations may also lead to simplistic or normative views of transitions: ‘One sometimes gets the idea that the change that really matters is truly dramatic change, the overturning of big systems. [. . .] Yet we should take care here. Our concern should be solving societal problems not tilting at “systems”’ (Meadowcroft, 2009: 337). To address this limitation, our conceptual elaborations and our empirical investigations will explicitly accommodate incremental change and more substantial adjustments in *existing* systems.

A fifth limitation is that existing socio-technical systems and incumbent actors are sometimes presented as inert monolithic entities, which overlooks the possibility of internal tensions and endogenous change (Jørgensen, 2012; Turnheim and Sovacool, 2020). This limitation relates to the first one, discussed previously: if one focuses on niche-innovations as drivers of transitions, then existing systems easily become seen as static barriers to be overcome. To address this limitation, we will elaborate the notion of the ‘semi-coherence’ (Geels, 2002) of existing systems, and, on the one hand, acknowledge disagreements, tensions, and ongoing dynamics in existing systems but, on the other hand, accommodate the relative stability and lumpiness of techno-economic elements, social networks, and institutions.

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

2.2 Reconfiguration of *Existing* Socio-Technical Systems

To address the limitations of the bottom-up 'innovation journey' approach to transitions, this section provides a complementary perspective on reconfiguration dynamics in *existing* socio-technical systems. Although these systems and associated actors are stabilised by lock-in mechanisms, they are not inert and can change over time. Drawing on several different literatures, we here elaborate the MLP by developing new conceptualisations of reconfiguration in techno-economic elements, actors, and rules and institutions.

2.2.1 Techno-Economic Reconfiguration

Socio-technical systems have techno-economic and material dimensions, which include artefacts, material goods, infrastructures, factories, and flows of inputs and outputs through supply chains. These include energy flows, which can be represented with Sankey diagrams (Cullen and Allwood, 2010), which show how energy inputs (e.g., oil, gas, coal, nuclear, renewables, biomass) feed into conversion devices (e.g., engines, motors, burners) to heat or power passive systems (e.g., vehicles, appliances, or buildings) to deliver final services (such as passenger transport, thermal comfort, sustenance, or hygiene). But they also include material consumption (e.g., steel, coal, plastics, concrete) and many technical components such as signalling systems for railways, transmission and distribution grids for electricity, road infrastructures and gas pipelines, and electronic information provision systems at bus stops, which are not represented in Sankey diagrams because of their focus on energy flows and conversion.

Existing socio-technical systems are stabilised by economic lock-in mechanisms such as sunk investments, economies of scale (Arthur, 1989), and competitive economic characteristics (e.g., low price, high performance) that make it difficult to dislodge them in mainstream markets (Arthur, 1989; Dosi, 1982). Artefacts, infrastructures, and factories also have material 'hardness' and momentum (Hughes, 1994) because of obduracy (Hommels, 2005) or complementarities between components and sub-systems (Rycroft and Kash, 2002). Despite these lock-in mechanisms, material system elements are not static and inert but usually evolve gradually through incremental technical changes and economic alterations in relative size, output, or market share (e.g., increasing car sales, road infrastructure length, or coal-fired electricity production). Deeper techno-economic reconfiguration is possible, as we will discuss after introducing some system coupling ideas.

From a technical systems perspective, it is useful to distinguish between components and the architecture of linkages between components. Components can be tightly or loosely coupled (Simon, 1973). In tightly coupled systems, a change in one component is likely to trigger or require changes in other

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

components. Loose coupling means that components are organised as independent modules, which can operate (relatively) independently of the detail of other components; they are only connected through functional inputs and outputs. Loose coupling permits modular innovations, which are improvements or replacements within one component without requiring synchronous changes in other components that make up the system. Modular innovation thus enables distribution of labour, specialisation, and flexible innovation (Baldwin and Clark, 1997; Robertson, 1992).

Building on these ideas, Henderson and Clark (1990) proposed that innovation in *existing* systems can be directed at components, architectures, or a combination of both, leading them to propose a typology with four kinds of innovation in technological products. We follow McMeekin et al.'s (2019) elaboration, which makes the typology more suitable to socio-technical systems by slightly changing the conceptual labels to 'modular incrementalism', 'modular substitution', 'architectural stretching', and 'architectural reshaping', and by differentiating the 'modular substitution' category to accommodate three different kinds of (partial) replacement:

- System-to-system switching results from competition between *existing* systems or dominant technologies, leading the former to decline and the latter to increase in size or output (Raven and Verbong, 2007). A modal switch from auto-mobility to railways is one example; a shift from coal- to gas-fired power is another.
- Niche-to-system hybridisation means that niche-innovations are added to and incorporated in existing systems (Berkers and Geels, 2011; Geels, 2002; Raven, 2007), leading to partial replacement of unsustainable components. Possible examples include the co-firing of biomass and coal, the blending of biofuels in petrol, hybrid electric vehicles.
- Niche-to-system replacement means that niche-innovations substitute particular (sub)system components. Examples include solar-PV or wind turbines replacing coal-fired power plants in the electricity generation sub-system; electric vehicles replacing diesel or petrol cars; heat pumps replacing gas boilers.

Based on these considerations, we propose Table 2.1, which we will use in the empirical chapters to analyse techno-economic reconfiguration of existing (sub) systems. One implication is that whole system reconfiguration involves multiple change mechanisms, which can all contribute to GHG emission reduction. The empirical chapters will try to identify the relative importance of different kinds of changes in unfolding low-carbon transitions in UK electricity, heat, and mobility systems. Another implication is that this conceptualisation changes the transition imagery from singular 'bottom-up' disruption towards a greater variety of reconfiguration pathways, including more gradual and dispersed reconfiguration.

We will not only use Table 2.1 to map and categorise different low-carbon innovations but also to diagnose temporal developments such as spillovers, knock-on effects, or innovation cascades between innovation categories

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

Table 2.1. *Analytical framework to map techno-economic reconfigurations of existing systems (adapted from McMeekin et al. (2019: 1226))*

	Core elements reinforced	Core elements substituted		
Architecture unchanged (linkages between components)	*Modular incrementalism*	*Modular substitution*		
		System-system switching	Niche-system hybridisation	Niche-system replacement
Architecture changed	*Architectural stretching*	*Architectural reshaping*		

(Berkers and Geels, 2011). For example, modular substitutions in the electricity generation sub-system (e.g., solar-PV and wind replacing coal) can trigger subsequent innovations in the electricity grid and consumption sub-systems (e.g., battery storage, back-up capacity, smart grids, or demand-side response), which may lead to architectural reshaping.

We will also use Table 2.1 to assess the *speed* and *scope* of techno-economic low-carbon transitions in electricity, heat, and mobility systems. We will assess *speed* by empirically analysing the deployment and market diffusion of different low-carbon innovations. We will assess *scope* by diagnosing the relative speeds and degrees of activity across the four different innovation categories. Substantial scope means that there is much activity and deployment in all four categories, whereas limited scope implies that activity is more concentrated on particular kinds of innovations.

2.2.2 Reorientation of Mainstream Actors

The material elements of existing socio-technical systems do not function autonomously but are the outcome of activities of incumbent and mainstream actors such as manufacturing firms, suppliers, policymakers, users, and civil society groups (Geels, 2004). Because incumbent actors repeatedly interact with each other, their networks and relations can be characterised as organisational fields (Geels, 2020b). 'The concept of field identifies an arena (a system of actors, actions, and relations) whose participants take one another into account as they carry out interrelated activities' (McAdam and Scott, 2005: 10). Field boundaries are not fixed and 'the players that populate the field and the nature of their play can change over time' (Davis and Marquis, 2005: 337).

There is always something at stake in organisational fields and field actors occupy varying positions, which are differentially advantageous in terms of economic resource flows, political power, or socio-cultural influence. While some

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

interactions are routinised, these differences in position give rise to strategic jockeying for position and ongoing struggles in existing organisational fields (Hoffman, 1999), both between incumbents and between incumbents and challengers. Fligstein and McAdam (2012: 3) suggest that 'constant low-level contention and incremental change are the norm in fields'.

For socio-technical systems, this implies that some degree of flux and incremental change is normal, leading to gradual adjustments and incremental trajectories in technology, markets, user practices, policies, and infrastructures (Geels, 2004). Larger changes and reorientations are more challenging and rare, however, because incumbent and mainstream actors are embedded and locked-in in various ways. To better understand these lock-ins and possible reorientations, we develop a multi-dimensional view on actors that draws on the configurational approach in organisation theory and generalises its logic to other actors.

Configurational approaches in organisation theory understand organisations holistically as a constellation of interconnected elements or dimensions that cluster together in particular patterns or archetypes, which have a substantial degree of stability and lock-in (Doty et al., 1993; Fiss et al., 2013; Ketchen et al., 1993; Meyer et al., 1993; Miller, 1996, 1990). Although there are ongoing debates about the specification of the organisational elements, many scholars (Gavetti and Rivkin, 2007; Greenwood and Hinings, 1996, 1993; Tushman and Romanelli, 1985) have proposed that organisational configurations have a hierarchical structure that, at least, involve the following dimensions: 1) core beliefs, goals, and interpretations (which are *cultural-cognitive categories* that provide overall or strategic direction and make sense of the organisation in its contexts), 2) capabilities, knowledge, and skills (which provide organisations with *abilities and resources* to perform certain tasks and innovate), 3) routines, habits, and operating procedures (which provide *behavioural templates* for standard operations and tasks).

Following Geels (2021), we propose that this logic of multiple hierarchically structured dimensions can be generalised from business organisations to other kinds of mainstream actors in socio-technical systems, although there are obvious differences between them, and the logic is perhaps somewhat tenous for wider publics, which are more dispersed and less task-oriented. This generalisation provides a multi-dimensional conceptualisation of important actors in socio-technical systems (firms, policymakers, users, wider publics), which acknowledges coherence and lock-in but also allows for reconfiguration (because the specified elements are not fixed 'hard cores'). Building on Geels' (2021) mobilisation of different disciplinary literatures, we aim to instantiate and exemplify this logic for different social groups but refrain from a deeper theoretical discussion, as this would hamper the argumentative flow. We first discuss the different dimensions for important actor groups and then briefly address change and depth of reorientation.

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

- For business actors, the following theories instantiate the three dimensions: 1) cognitive and interpretive management theories perceive core beliefs, mission, or mindset as the most foundational dimensions that guide the strategies and actions of firms in particular directions (Gavetti, 2005; Phillips, 1994); 2) the resource-based view of the firm (Barney, 1991) and evolutionary economics (Nelson and Winter, 1982) see technical knowledge and capabilities as core enablers and strategic assets of firms; 3) the behavioural theory of the firm suggests that day-to-day activities are guided by routines, rules of thumb, and standard-operating procedures (Cyert and March, 1963).
- For policy actors, the following theories instantiate the three dimensions: 1) policy paradigm theory suggests that policy goals, worldviews, problem framing, and governance styles guide policymaking in particular directions (Hall, 1993); 2) historical institutionalism argues that institutional arrangements (e.g., access rules, agenda-setting procedures, political 'rules of the game'), policy networks, and knowledge enable and structure policymaking processes and political struggles (Thelen, 1999); 3) the theory of (disjointed) incrementalism suggests that most day-to-day policymaking consists of small adjustments in the settings of existing policy instruments, because civil servants use heuristics and routines in the cycle of policy formulation, implementation, evaluation, and adjustment (Lindblom, 1979; Weiss and Woodhouse, 1992).
- For users, the following theories instantiate the three dimensions: 1) convention theory highlights the role of socio-cultural frames, value systems, and 'orders of worth' in user evaluations (Boltanski and Thévenot, 2006; Wilkinson, 2011), while sociologists proposed the term 'doxa' to refer to society's taken-for-granted, unquestioned truths that underpin understandings of normality and normal behaviour (Bourdieu, 1977); 2) social practice theory proposes that people purchase and use products in the course of engaging in daily life practices, which are stabilised clusters of activities involving multiple elements, including competencies, meanings, and materials (Shove et al., 2012; Warde, 2005); 3) social psychological theories suggest that day-to-day user behaviour is shaped by habits, routines, and heuristics, which do not require conscious thought and thus help people save time and energy (Maréchal, 2010).
- For public debates, the following discourse theories instantiate the three dimensions: 1) cultural sociology (Alexander, 2003) and macro-cultural discourse theory (Lawrence and Phillips, 2004) suggest that cultural deep structures such as symbolic categories, cultural repertoires or ideographs such as 'freedom', 'democracy', 'progress', or 'sustainability' (McGee, 1980) undergird and steer public debates in particular directions; 2) critical discourse analysis draws attention to more specific discourses, which are 'ensembles of ideas, concepts, and categories through which meaning is given to social and physical phenomena' in

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

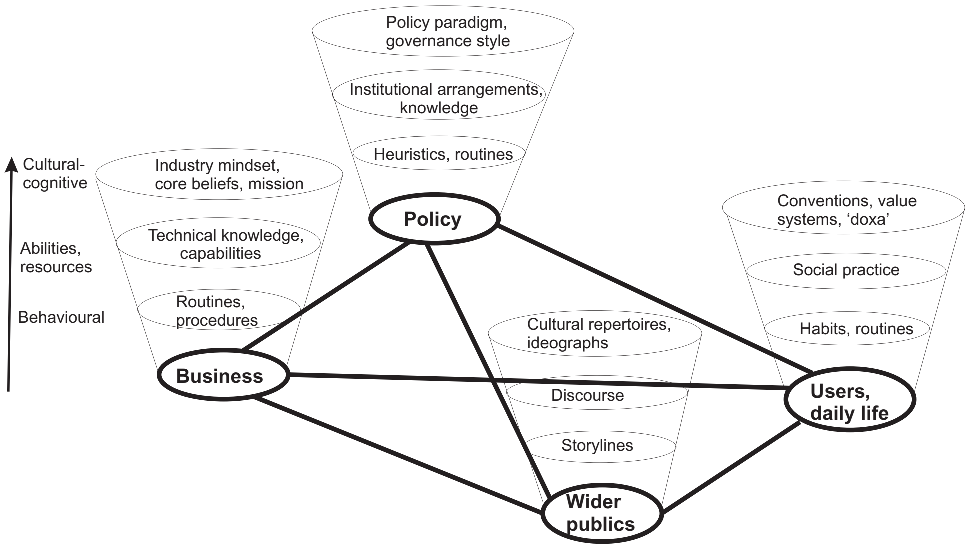

Figure 2.2 Configurational dimensions of incumbent actor groups (Geels, 2021)

a particular domain of practice (Hajer and Versteeg, 2005: 175) and the interests and power relations behind these discourses (Fairclough, 1995); 3) argumentative and rhetorical discourse theory focuses on the storylines, metaphors, slogans, and catchphrases that participants use in specific debates, which they incrementally adjust in response to each other's claims and arguments (Heracleous and Marshak, 2004).

Figure 2.2 schematically summarises the main elements at the three configurational dimensions for each actor group. One advantage of this novel conceptualisation is that it accommodates multiple kinds of agency, including boundedly rational strategic action through which actors aim to achieve goals and advance their interests (which need to be interpreted and can change over time), routine-based action, learning and knowledge development, and strategic sense-making.

Another advantage is that this conceptualisation makes it relatively straightforward to understand different *depths* of actor reconfiguration as involving changes in different dimensions: substantial reconfiguration involves changes in cultural-cognitive beliefs, repertoires, conventions, or policy paradigms; moderate-depth reconfigurations involve changes in technical capabilities, social practices, discourses, or institutional arrangements; and limited-depth reconfiguration involves changes in routines, habits, and standard-operating procedures, which happen relatively frequently, generating incremental change. Deeper changes are more transformative but also rarer and more difficult.

A third advantage is that this conceptualisation allows for differentiation within organisational fields and the possibility that different actor groups reconfigure to

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

different degrees and depths (which we will empirically analyse for different systems). A fourth advantage is that this conceptualisation of actors endogenises cultural-cognitive dimensions, which we, for the purpose of this book, exclude from our conceptualisation of rules and institutions (further discussed next). It thus makes these cultural-cognitive dimensions less free-floating and less consensually shared between all actor groups than in some neo-institutional theories.

This novel conceptualisation thus makes it possible to further develop the increasing recognition that transitions do not only result from new entrants overthrowing incumbents (which follows a heroic 'David versus Goliath' plotline) but can also be enacted by incumbent actors who reorient from existing systems towards niche-innovations (Bergek et al., 2013; Berggren et al., 2015; Penna and Geels, 2015; Turnheim and Geels, 2019).

Such reorientation is not easy, because it involves overcoming various lock-in mechanisms. Especially for core beliefs and capabilities, actor reorientation therefore usually requires: 1) increasing external pressures, 2) decreasing beliefs in the viability of the status quo, and 3) perceptions of attractive opportunities towards which actors can reorient (Geels and Penna, 2015; Turnheim and Geels, 2013). The development of a comprehensive reorientation framework for all actor groups is beyond the book's ambition. For our empirical analyses of incumbent actor reorientation in electricity, heat, and mobility systems (in Chapters 4, 5, and 6), we mainly aim to describe and map the *depth* of reorientation by different actor groups and identify some salient drivers. We will use Figure 2.2 as a heuristic framework for this empirical mapping. We do not assume beforehand that all incumbent actor groups are reorienting in equal depth in unfolding low-carbon transitions. In fact, we will investigate reorientation depths for different actor groups and the transition patterns that result from this.

As to the directionality of change, our empirical analyses also do not assume that climate change is the only issue to motivate actor reorientation. In fact, we assume and will empirically show that incumbent actors in UK electricity, heat, and mobility systems are historically more concerned about other issues such as congestion, road safety, parking, domestic manufacturing and jobs, prices, energy security, energy poverty, and housing shortages. So, to comprehensively understand the depth of low-carbon reorientation of incumbent actors, we will not only analyse their climate mitigation strategies and activities but also other issues that concern them and the associated activities, which may hamper their engagement with climate mitigation.

2.2.3 Policy Reconfiguration

Actors and activities in organisational fields are shaped (but not determined) by rules and institutions (Powell and DiMaggio, 1991). Building on neo-institutional

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

theory (Powell and DiMaggio, 1991; Scott, 1995; Thornton et al., 2012), previous conceptualisations of rules and institutions in socio-technical transitions research distinguished regulative, normative, and cultural-cognitive institutions (Geels, 2004) or used the institutional logics concept (Fuenfschilling and Truffer, 2014; Smink et al., 2015). But the three types of institutions are easier to distinguish conceptually than to investigate empirically, and the institutional logics concept has been criticised as too all-encompassing and too consensual:

> The use of the term "institutional logics" tends to imply way too much consensus in the field about what is going on and why and way too little concern over actors' positons, the creation of rules in the field that favour the more powerful over the less powerful, and the general use of power in strategic action fields. [. . .] We see fields as rarely organized around a truly consensual "taken for granted" reality. [. . .] In contrast, for us, there is constant jockeying going on in fields as a result of their contentious nature. (Fligstein and McAdam, 2012: 12)

For the purpose of this book, we therefore draw more on 'old' institutional theories that focus on formal-regulative institutions such as laws, regulations, standards, financial incentives, and subsidy schemes, which act as legally sanctioned 'rules of the game', as well as governance structures and the role of the state (Hirsch and Lounsbury, 1997; North, 1990). To not exclude cultural-cognitive dimensions from our overall analysis, we have accommodated them in our conceptualisation of incumbent actor groups, as described previously.

Our focus on formal policies and governance style implies that we see policymakers as having special responsibilities and resources in governing organisational fields and socio-technical systems (see also Scott et al., 2000). This also resonates with the empirical reality that electricity, heat, and mobility systems are highly regulated systems with salient roles for policymakers, ministries, and regulatory agencies. It further resonates with the fact climate change is an externality for actors in these socio-technical systems and that public policies will therefore be essential to drive their low-carbon reconfiguration.

Policy reconfiguration for low-carbon transitions is a struggle because existing electricity, heat, and mobility systems already have many policies and governance arrangements in place. Many of the existing policies and arrangements are tailored to incumbent interests and oriented towards non-climate goals such as congestion, road safety, domestic car manufacturing in (auto)mobility, energy security or prices in electricity, and energy poverty and boiler safety in heating. Low-carbon transitions thus require the new issue of climate change to be integrated into existing policies and governance structures. To further conceptualise this struggle, we build on the literatures of environmental policy integration (EPI), climate policy integration (CPI), and policy mixes.

The basic idea behind EPI, which goes back to the 1990s, is that environmental problems cannot be fully addressed by environmental ministries but that this

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

requires involvement from the sectors that drive and cause the environmental problems. EPI thus involves the mainstreaming or 'incorporation of environmental objectives in non-environmental policy sectors, such as agriculture and transport, rather than pursuing environmental protection through specialised environmental policies and legislation by environmental institutions. In this way, EPI aims to target the underlying driving forces rather than symptoms of environmental degradation' (Persson and Runhaar, 2018: 141).

EPI is not easy, however, because it involves the integration of 'a traditionally less prioritized policy objective, typically supported by less powerful actors, into "mainstream" sector objectives, typically supported by well-organized interests. This sets the stage for resistance from incumbents which arguably requires significant political will to be overcome' (Nilsson and Persson, 2017: 37).

Policymakers in electricity, heat, or mobility systems may (initially) find environmental or climate change issues less important than existing sector-specific goals. Because they are locked-in by prevailing routines, institutional arrangements, and policy paradigms (as discussed in Section 2.2.2), policymakers in these systems may be reluctant to accommodate the new issue, as Jordan and Lenschow (2010: 153) explain:

> At the administrative level, contention arises from distinct cultures and routines in the bureaucratic segments of an administration and from the 'rational' inclination of each part to protect its competences, resources and ways of doing from the intervention of other parts. At the end of the day, greater policy integration does often require political leadership from above.

Although the *principle* of EPI enjoys broad policy support, actual implementation has remained limited because of these contentions. In their state-of-the-art review, Jordan and Lenschow (2010: 153) conclude that: 'With the exception of a very few cases, EPI is pursued as an "add-on" rather than as a process that challenges the underlying rationale for spending public money on unsustainable practices. [. . .] While governments have undoubtedly extended their repertoire of instruments, they have done so in a largely piecemeal fashion'. Nilsson and Persson (2017: 36) similarly conclude that EPI initiatives 'rarely result in having significant impact on policy but tend to get stuck at the level of policy statements'.

Drawing on the limited set of positive cases, Persson and Runhaar (2018) identified several external success factors for EPI that create pressure on policymakers: 1) public awareness and support for addressing an environmental issue, 2) stakeholder and interest group support, 3) support by other governmental actors, and 4) compatibility with pre-existing sectoral policy frames. They also identified several internal success factors: 1) political will, 2) overlap with sectoral objectives, 3) perceived urgency of the issue to be integrated, 4) overarching policy

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

frameworks, and 5) organisational provisions for intersectoral cooperation, leadership, and resources.

Climate policy integration (CPI), which is a subset of EPI, has been relatively more successful (Di Gregorio et al., 2017; Dupont, 2016), as indicated by substantial increases in legislative activity within particular sectors, although Schmidt and Fleig (2018) find more CPI activity in energy than in transport. This greater success of CPI is partly due to the strengthening of several of the external and internal success factors that were discussed earlier. But it is also due to three specific differences identified by Adelle and Russel (2013: 9): 1) CPI is narrower and more tangible than the broader and vaguer concept of EPI, 2) CPI outputs are more easily measured (e.g., as GHG emissions or diffusion of green technology) and easier to communicate in a media friendly way than the less appealing administrative processes associated with EPI, and 3) CPI is less about expansive integration across all policy sectors and more about engaging a narrower set of sectors to work together to meet specific goals.

Building on the EPI and CPI literatures, we conclude that institutional low-carbon reconfiguration is possible but challenging because the integration of climate change objectives into existing policies and governance styles is likely to encounter various hurdles that require internal and external pressures to be overcome.

The policy mix literature offers further relevant insights for analysing institutional reconfiguration. This literature distinguishes between two analytical levels: 1) policy strategies, including policy goals and governing styles, and 2) policy instruments (Rogge and Reichardt, 2016). It understands policy mixes as 'complex arrangements of multiple goals and means which, in many cases, have developed incrementally over many years' (Kern and Howlett, 2009: 395). It also proposes useful concepts to analyse the interplay between multiple goals and instruments in a policy mix (Rogge and Reichardt, 2016; Schmidt and Sewerin, 2019), including: 1) the *coherence* of policy goals (i.e., the degree to which they contradict each other), 2) the *consistency* of policy instruments (i.e., the degree to which they reinforce or undermine each other in achieving policy goals), and 3) *comprehensiveness* of policy instruments (i.e., the balance of *types* of instruments). With regard to the latter, Schmidt and Sewerin (2019: 3) observe that: 'An unbalanced policy mix that relies on one or a few instrument types is less likely to address all issues and reach all relevant actors. Consequently, it is less likely to be effective'. Relevant instrument types for low-carbon transitions typically include financial incentives, regulatory instruments, information instruments, and direct government investments (Grubb, 2014).

Policy mixes in particular domains are rarely designed from scratch. Instead, they 'more often than not evolve through layering of potentially incoherent policy goals and inconsistent instruments over time' (Kern et al., 2019: 2).

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press

Combining these ideas with the EPI/CPI literatures, we propose that climate change goals and policy instruments are initially likely to be layered on top of existing system-specific policy goals and instruments. This layering often results in an incoherent policy mix, which will be relatively ineffective if climate goals or policies remain singular and isolated 'add-ons' to the existing policy mix (Howlett and Rayner, 2013). To advance low-carbon transitions, it will be necessary to make deeper reconfigurations in policy goals, governance styles, and instruments so that the system-specific policy mix becomes more coherent, consistent, and comprehensive. The *depth* of institutional low-carbon reconfiguration thus depends on the elevated importance of climate mitigation goals and alignment with system-specific policy goals, changes in governance style (e.g., from hands-off to interventionist approaches; from piecemeal to systemic approaches), and increases in the number, stringency, and types of climate mitigation instruments.

Our empirical analyses will map the varying depths of institutional low-carbon reconfiguration in electricity, heat, and mobility systems. They do not aim to systematically explain these differences, although external and internal causes may be inductively alluded to.

https://doi.org/10.1017/9781009198233.003 Published online by Cambridge University Press