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Introduction

1.1 The Need for Low-Carbon System Transitions and a Reconfigurational Approach

Climate change is a grand societal challenge that in the coming decades will increasingly affect many aspects of society either through its impacts (e.g., droughts, floods, crop failures, fires, sea level rise, heat stress) or through mitigation efforts that attempt to transform energy, mobility, industrial, and agri-food systems in low-carbon directions (IPCC, 2018).

Recognition of the seriousness of these threats and the scale of the mitigation challenges has increased public attention to climate change since the mid-2000s (see Figure 1.1), fuelled by events such as Hurricane Katrina (2005), Al Gore's movie *An Inconvenient Truth* (2006), the Stern Review (2006), and the Fourth IPPC Assessment Report (2007). Public attention decreased after the 2007/8 financial crisis, but has increased again in recent years, along with highly publicised events such as the Paris Agreement (2015), protests by school children and civil society organisations (e.g., Extinction Rebellion, Climate Justice movement), and new framings such as 'climate emergency' since 2019.

In response, an increasing number of countries have adopted net-zero greenhouse gas (GHG) emission targets, and broadened and strengthened their low-carbon transition plans. Public attention remained high throughout the COVID-19 pandemic, creating pressures on policymakers, although there is an indication of a slight decrease in coverage during 2020, due to competing societal issues related to the pandemic.

It is now widely recognised that achieving net-zero targets will require system transitions in core societal domains. The Intergovernmental Panel on Climate Change (IPCC), for instance, calls for 'rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems. These systems transitions are unprecedented in terms of scale, but not

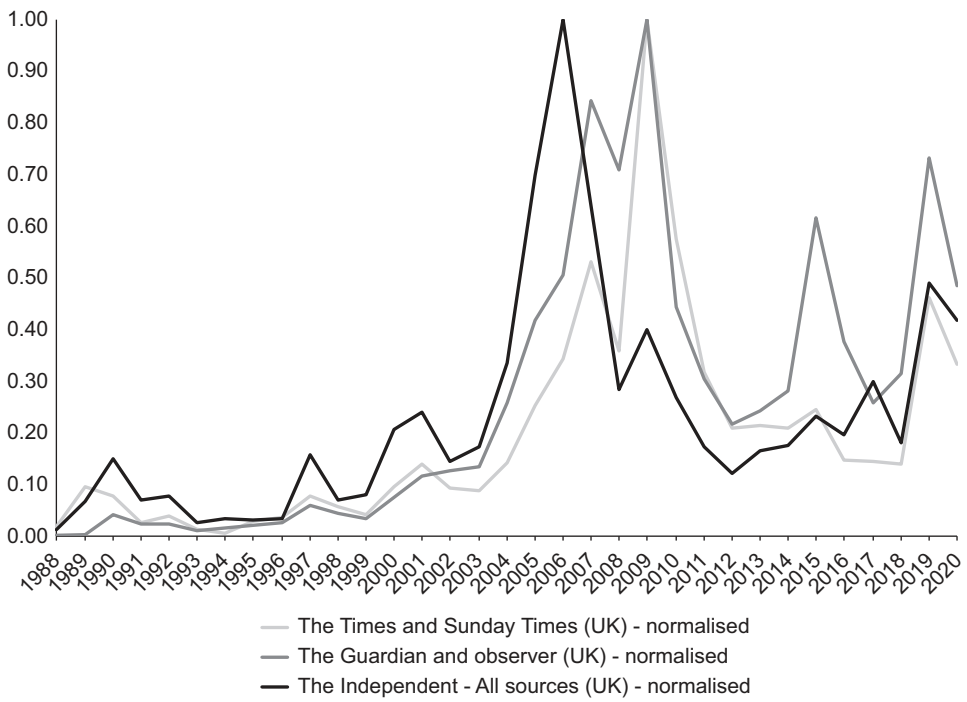

Figure 1.1 Yearly number of articles in selected UK national newspapers related to climate change (the graph is based on data from a keyword search in the digital archives of these newspapers, using the search string [Text, 'climate change' OR 'global warming' OR 'global heating' OR 'greenhouse effect' OR 'greenhouse gas' OR 'climate emergency' OR 'climate crisis' OR 'decarbonisation' OR 'decarbonization' OR 'low-carbon'] within the title and first hundred words of the articles. Duplicated articles were excluded. To facilitate visual comparison between different data sets, we normalised the time series to the year with the maximum number of counts)

necessarily in terms of speed, and imply deep emission reductions in all sectors' (IPCC, 2018: 21).

The European Commission's long-term climate strategy likewise acknowledges that:

> economic and societal transformations are required, engaging all sectors of the economy and society, to achieve the transition to net-zero greenhouse gas emissions by 2050. . . . This transition will radically transform our energy system, land and agricultural sector, modernise our industrial fabric and our transport system and cities, further affecting all activities of our society.
>
> *(EC, 2018: 5–6)*

The European Environment Agency (EEA) also assesses that addressing climate change (and other persistent environmental problems) 'will require fundamental

transitions in core production-consumption systems such as those meeting European demand for food, energy, mobility and housing. Such transitions will necessarily entail profound changes in dominant institutions, practices, technologies, policies, lifestyles and thinking' (EEA, 2019a: 7).

While the need for low-carbon system transitions is now widely acknowledged, there is disagreement, however, in both public and academic debates, about *what system transitions are and how they come about*. Building on Geels et al. (2015), we distinguish three analytical approaches that resonate with different scientific theories and policy approaches: 1) reform, 2) revolution, and 3) reconfiguration.

The *reformist* approach, which can be found in engineering, modelling, and mainstream economics (Acemoglu et al., 2016; Dangerman and Schellnhuber, 2013; Hawken, 2017; Rockström et al., 2017; Stiglitz et al., 2017), conceptualises transitions as driven by the development and market adoption of low-carbon technologies that substantially lower the carbon-intensity of existing provisioning systems in energy, mobility, food, and industrial production. It sees research and development (R&D), subsidies (to stimulate new technologies), and carbon pricing instruments (to influence company investment decisions and consumer purchases) as the main policy instruments. This approach is 'reformist' because it assumes that low-carbon transitions only involve technical component substitution and do not affect other elements of transport, energy, and agri-food systems. Because the approach assumes that the technological substitutions mainly involve rational economic decisions by firms, investors, and users, it also does not pay much attention to political, social, or behavioural dimensions.

While the reformist position rightly emphasises the importance of low-carbon technologies, investments, and markets, it also has several limitations: 1) it has an over-simplistic 'linear model' understanding of innovation as 'pushed' by upstream R&D investments and 'pulled' by downstream market demand (Schot and Steinmueller, 2018), 2) it pays little attention to non-technological kinds of innovations such as social, business model, and grassroots innovations, 3) it pays too little attention to non-market actors such as wider publics, civil society organisations, industry associations, and other lobby organisations, 4) it also pays too little attention to various forms of agency and processes such as institutional change and power struggles, business activities and strategic games, cultural meanings, and demand-side dynamics in social practices.

The *revolutionary* approach, which involves multiple sub-streams that share deep critiques of the status quo and current policymaking, views low-carbon system transitions as involving the complete overhaul of socio-economic deep structures. Neo-Marxist (Schnaiberg, 1980) and critical political economy scholars (Newell, 2021; Paterson and P-Laberge, 2018), for example, highlight the need to overthrow or transform capitalism (particularly its focus on commodification,

market competition, and capital accumulation) and neo-liberalism (particularly its faith in free markets). Scholars within revolutionary strands have proposed a 'new economics' (Schor, 2014) that includes 'de-growth' (Kallis, 2011), more emphasis on third sector and community-based enterprise (Jackson and Victor, 2011), a shift from GDP measures towards happiness (Gough, 2010), and returning the globalised financial system to 'its role as servant, not the master of the economy and ecosystems' (Pettifor, 2019). Cultural and moral critics also call for changes in consumer society and underpinning values, which should be transformed in the direction of frugality and sufficiency (Alcott, 2007; Princen, 2005) or towards 'meaningful' activities such as 'fine education, arts, healthcare, childcare and elderly services, [. . .] and community development' (Vergragt, 2013: 124). These cultural value changes have been characterised as The Great Mindshift (Göpel, 2016) or The Great Transition towards a new planetary civilisation, which involves a 'fundamental shift in the paradigm of development – indeed, in the very meaning of human progress. A Great Transition would make solidarity, fulfilment, and resilience the heart and soul of human endeavour' (Raskin, 2016: iii).

While the revolutionary position rightly draws attention to macro-economic and macro-cultural issues, it also has several limitations. First, these assessments of macro-level 'deep structures' are often reductionist because they try to bring complex realities back to single 'root causes'. Second, they tend to be rather abstract and distanced from concrete experiences of real-world actors. Many, though not all, critical analyses of capitalism or neo-liberalism are disempowering because their focus on an 'all-encompassing entity can easily come to appear as a kind of gigantic, all-powerful [. . .] force that causes everything else to happen' (Ferguson, 2010: 171), which is difficult to alter by situated actors. Third, macro-level analyses of capitalism lack the explanatory granularity to satisfactorily explain why some sectors, such as electricity, have made much more decarbonisation progress than other sectors, such as heat.

Fourth, despite their interest in fundamental change, some sub-streams in the revolutionary position are paradoxically static, restricting analysis to critiques of deep structures or advancing utopian visions of communitarian, local, and sustainable societies. These sub-streams thus offer little insight about change mechanisms or dynamic pathways that could bring about the desired system transitions. Other revolutionary sub-streams place high hopes on the transformative power of community initiatives, grassroots innovations, or social movement activism, but often fail to articulate how local initiatives bring about large-scale system change. Steward (2018: 100) in this regard notes that 'Such case studies [of community activism] are certainly impressive and inspiring. However, they do not demonstrate to academic critics that this is a route for a transition to a low-carbon society at a broader level'. O'Brien and Signa (2018: 40) similarly observe an analytical gap between local initiatives and large-scale transformation, noting that

there are many studies of the former but few of the latter, 'There are (as yet) relatively few empirical examples of successful large-scale transformations of socio-ecological systems towards sustainability.' These strands in the revolutionary position therefore suffer from a 'lack of empirical grounding' (Feola, 2015: 377), which means that related interpretations of system transition remain more normative and political than analytical.

Because of the limitations of the reformist and revolutionary approaches, this book mobilises a *reconfiguration* approach, which builds on the general scientific notion that 'the whole is best understood from a systemic perspective and should be viewed as a constellation of interconnected elements' (Fiss et al., 2013: 2). Instead of privileging an ultimate cause, reconfigurational approaches imply a commitment to multidimensional analysis that traces endogenous interactions between multiple components and processes that together produce larger outcomes: 'What makes configurational thinking unique is its insistence on putting particular pieces together into larger wholes' (Abbott, 2001: 119). Reconfigurational approaches are particularly suited for analysing changes in large-scale systems made up of heterogeneous entities (see Section 3.1), and they often involve processual analyses that explain how outcomes are produced through co-evolving causal processes: 'This interest in combinations of causes dovetails with a focus on "how" things happen [. . .] to understand causally relevant conditions as intersections of forces and events' (Ragin, 2008: 109).

With regard to low-carbon system transitions, the reconfiguration approach has been particularly developed in socio-technical transitions research, which focuses on deep changes to socio-technical systems that fulfil societal functions such as mobility, thermal comfort, or sustenance. Drawing on sociology of innovation and evolutionary economics (Geels, 2020b, 2004), socio-technical systems are conceptualised as heterogeneous configurations of elements including technical artefacts, scientific knowledge, industry structures, markets, consumption patterns, infrastructure, policy, and cultural meanings (Figure 1.2).

In this book, we build on socio-technical transitions research and conceptualise low-carbon system transitions as involving substantial changes in both the elements of socio-technical systems and the architecture of their linkages (Geels et al., 2017). Taking innovation (in technologies, business models, social practices) as the analytical *entrance point*, the socio-technical transitions approach follows the emergence, diffusion, and societal embedding of innovations over time and analyses the relevant interactions between technical, social, cultural, political and economic processes and actors (Geels, 2005). Socio-technical transitions have the following characteristics (Köhler et al., 2019):

- *Multidimensionality and co-evolution*: Transitions are co-evolutionary processes involving interactions between multiple socio-technical dimensions. Because it

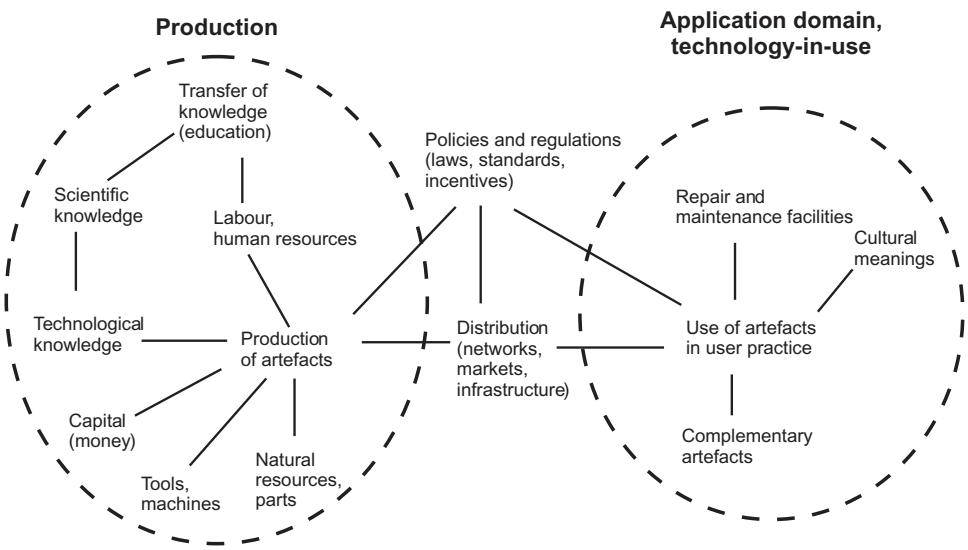

Figure 1.2 Basic elements of socio-technical systems (Geels, 2004: 900)

does not privilege one driver or dimension, the reconfiguration position is less reductionist than both the reformist position (which focuses on techno-economic processes) and the revolutionary position (which focuses on macro-economic or macro-cultural 'root causes').

- *Multi-actor process*: Transitions are enacted not only by firms and users (as in the reformist position) but also by social movements, wider publics, policy-makers, industry associations, and other special-interest groups (Geels, 2004). These social groups have different interests and resources, and they engage in multiple activities (e.g., technological exploration and learning, public debates, political power struggle, investment, negotiation, coalition building) which make transitions very complicated processes that cannot be comprehensively understood by single theories or disciplines.
- *Goal-orientation*: Low-carbon transitions are particular kinds of socio-technical transitions because they aim to address environmental objectives rather than mere technical performance or economic objectives. This means that in addition to requiring deep and large-scale system changes, they involve the additional challenge of securing a particular directionality (Kemp and van Lente, 2011). Therefore, policymakers must play a central role in low-carbon transitions by adjusting institutions and policies, including regulations, standards, taxes, and subsidies.
- *Resistance, conflict, and struggle*: Since low-carbon transitions threaten the economic positions and business models of some of the largest and most powerful industries (e.g., oil, automotive, electric utilities, agri-food), such

incumbents will protect their vested interests, which may lead to conflict and struggle about the need for, and speed of, transitions and the types and stringency of policy instruments intended to advance them.

- *Long-term process*: Transitions are longitudinal processes that often take decades to unfold. One reason is that radical low-carbon innovations and practices usually take a long time to develop from their early emergence in small application niches to widespread diffusion. Another reason is that it takes time to destabilise and 'unlock' existing systems and overcome resistance from incumbent actors (Turnheim and Geels, 2012).
- *Non-linearity, uncertainty, and open-endedness*: Because there are *multiple* low-carbon innovations and initiatives in all socio-technical systems, it is difficult to predict in advance which of these will prevail. Since there are multiple possible transition pathways (Geels and Schot, 2007; Rosenbloom, 2017), future low-carbon transitions are open-ended. Uncertainty also stems from the non-linear character of innovation processes (which may experience failures, hype-disappointment cycles, or accelerated price/performance improvements), political processes (which may experience setbacks, reversals, or accelerations), and socio-cultural processes (which may experience changes in public agendas and sense of urgency).

These characteristics make socio-technical system transitions a special kind of phenomenon that requires a dedicated research approach. This book therefore aims to elaborate the socio-technical transitions approach, which has emerged in the past two decades in the innovation studies and sustainability transitions communities, and to introduce it into the mainstream climate mitigation debates. In doing so, it hopes to transcend the first two approaches that have long dominated mainstream environmental sustainability and climate mitigation debates, which has led to stale dichotomies between strong and weak ecological modernisation (Christoff, 1996) and strong and weak sustainable consumption (Fuchs and Lorek, 2005). Spaargaren and Cohen (2009: 257) criticised these traditional positions as overly limited, characterising them as 'the dark green romantic dismissal of modernity and the naïve endorsement of market driven liberal eco-technotopias'.

The book also aims to be relevant with regard to ongoing policy debates. The reformist approach is closely tied to the policy orthodoxy, which has long led climate policy debates to emphasise R&D subsidies and carbon pricing instruments to reorient financial investments (Energy Transitions Commission, 2017, 2016; IEA and IRENA, 2017; OECD, 2018; World Bank, 2015). While these generic economic policies are not irrelevant, the increasing emphasis on the *implementation* of low-carbon innovations and system transition is changing policy debates to focus more on specific innovations, the actors that develop and

deploy them, and their real-world social and political feasibility (Meckling and Allan, 2020).

The European Commission (EC, 2019), for instance, acknowledges that 'New technologies, sustainable solutions and disruptive innovation are critical to achieve the objectives of the European Green Deal' (p. 18), that 'conventional approaches will not be sufficient' (p. 18), and that 'there is a need to rethink policies for clean energy supply across the economy, industry, production and consumption, large-scale infrastructure, transport, food and agriculture, construction, taxation and social benefits' (p. 4). The IPCC (2018) emphasises that climate mitigation policies should address six feasibility dimensions (technological, economic, socio-cultural, institutional, geophysical, environmental-ecological) that shape the real-world implementation and acceptance of low-carbon transitions. And the UK Committee on Climate Change (2021: 33) calls for deeper understandings of real-world implementation processes and actors to support policymaking:

> As Government makes the shift to focusing on implementation, the Committee's task must also evolve towards a focus on real-world progress and tougher scrutiny of Government plans. [. . .] The transition to Net Zero requires changes that go beyond the deployment-related metrics we have tended to track to date. We will seek to broaden our assessment of real-world progress, including public attitudes, corporate commitments, finance and the green recovery, as well as consumption emissions and the factors affecting them.

The socio-technical transitions approach to whole system reconfiguration, which this book will develop, aims to contribute to these recent policy debates.

1.2 The Multi-Level Perspective on Socio-Technical System Transitions

To further conceptualise socio-technical system transitions, we use the Multi-Level Perspective (MLP), which is a middle-range theory that combines insights from evolutionary economics, sociology of innovation, and institutional theory (Geels, 2020b, 2002). The MLP suggests that socio-technical transitions result from the interplay of developments at three analytical levels: socio-technical systems, niche-innovations, and exogenous socio-technical landscape developments (Geels, 2019, 2002; Rip and Kemp, 1998).

Before discussing these levels and their interactions, we articulate some foundational assumptions which build on Geels (2004) who distinguished three interrelated analytical dimensions: 1) tangible elements of socio-technical systems, 2) actors and social groups whose actions maintain, improve, repair, and change the system elements (through research, technology development activities, purchasing, debates, policymaking), and 3) rules and institutions (often called 'socio-technical regime') that shape actors' preferences, strategies, and actions.

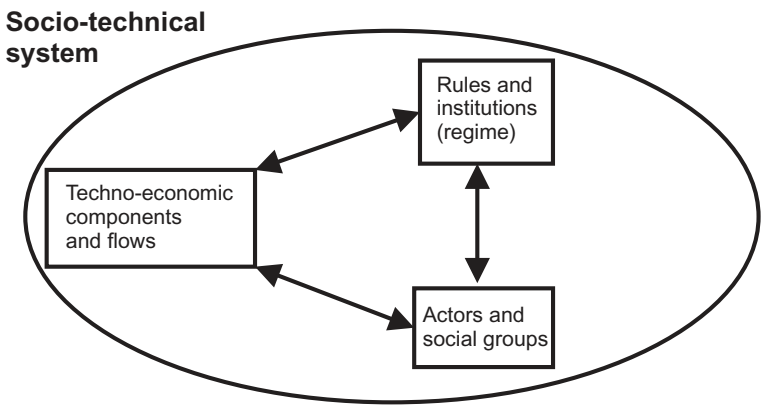

Figure 1.3 Three ontological dimensions of socio-technical systems (adapted from Geels, 2004: 903)

To facilitate interdisciplinary bridging conversations with technical, economic, and policy sciences (Cherp et al., 2018; Geels et al., 2016a; Turnheim et al., 2015) and increase relevance for policymakers, we make four simplifying adjustments in this conceptual scheme. First, rather than diffusely focusing on all tangible elements of socio-technical systems, we reformulate the first dimension of the distinction as listed in the preceding paragraph to focus more narrowly on material, technical, and economic elements and flows (e.g., artefacts, infrastructures, factories, flows of inputs and outputs). This resonates with, and gives more emphasis to, Geels' (2004: 904) observation that 'Technologies have a certain "hardness" or obduracy, which has to do with their material nature, but also with economic aspects. [. . .] This hardness also implies that artefacts cannot entirely be shaped at will.' This reconceptualisation also draws more analytical attention to the material and energy flows that sustain socio-technical systems.

As a second adjustment, we reconceptualise socio-technical systems as the entire configuration of the three analytical dimensions (Figure 1.3). This resolves the problem that the previous conceptualisation included three dimensions but had no concept to cover the whole configuration. This conceptualisation means that socio-technical systems have material, relational, and institutional dimensions.

As a third adjustment, we simplify the conceptualisation of rules and institutions, as Section 2.2.3 further explains. Previous conceptualisations (e.g., Fuenfschilling and Truffer, 2014; Geels, 2004), which build on neo-institutional theory (Powell and DiMaggio, 1991; Scott, 1995), distinguished three kinds of rules and institutions (regulative, normative, and cultural-cognitive) as enabling and constraining actors in different ways. *For the purpose of this book*, we simplify the conceptualisation to focus more narrowly on 'policies and governance structures', which is closer to the old institutional theory's understanding of

institutions as rules of the game (Hirsch and Lounsbury, 1997; North, 1990). This conceptualisation of institutions is easier to operationalise and investigate, and intrinsically leads to a stronger focus on policy and politics, which hopefully appeals to readers with a policy interest.

Since we do not want to exclude norms and cultural-cognitive dimensions from the analysis, our fourth adjustment is to endogenise these dimensions in our conceptualisation of actors, which also includes intendedly rational strategic action, behavioural routines, and capabilities, as Section 2.2.2 further explains.

These theoretical assumptions underpin and inform the conceptualisation of the three analytical levels of the MLP and the dynamics of socio-technical transitions, to which we now turn.

Existing *socio-technical systems* are stabilised by various lock-in mechanisms that constrain incumbent actors and orient their activities towards incremental rather than radical change. These include a) techno-economic lock-in mechanisms such as sunk investments, material obduracy, low cost and high performance characteristic, b) social and cognitive lock-in mechanisms such as routines, heuristics (Nelson and Winter, 1982), shared mindsets, habits, and lifestyles (Barnes et al., 2004), and c) institutional and political lock-in mechanisms such as existing regulations and standards that favour existing systems and create an uneven playing field for emerging innovations (Walker, 2000) as well as institutional procedures that give incumbents more access to policy networks, where they can influence policymaking and protect the status quo (Geels, 2014; Kolk and Pinkse, 2007). These lock-in mechanisms stabilise existing systems, which is why system transitions do not happen easily.

Radical innovations, which are the seeds of transitions, emerge in small *niches* at the periphery of existing systems, through pioneering activities of entrepreneurs, start-ups, activists, or other relative outsiders (Kemp et al., 1998). Niches form 'protected spaces' that shelter radical (technical, grassroots, and business model) innovations from mainstream market selection pressure and nurture learning and development processes (Smith and Raven, 2012). The degree of radicality of niche-innovations depends on how much they deviate from the existing system on technical, social, business model, or infrastructural dimensions.

The struggles between niche-innovations and existing socio-technical systems are influenced by the *socio-technical landscape* (Rip and Kemp, 1998), which includes both slow-changing states or developments (e.g., demographics, cultural repertoires, societal concerns, geo-politics, macro-economic trends) and external shocks (e.g., wars, financial crises, accidents, oil price shocks, pandemics) (Van Driel and Schot, 2005).

Socio-technical transitions are non-linear processes that occur through the interplay between processes at niche, system, and landscape levels, which unfold