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Perspectives on transitions to sustainability

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1 Introduction

1.1 Background

Systemic challenges and responses

The European Environment Agency's last five-yearly report on the European environment, *The European environment — state and outlook 2015* (SOER 2015), presented a mixed picture of the European environment's past trends and future prospects. Reflecting on progress in the 40 years since the initiation of European environmental policy in the 1970s, SOER 2015 concluded that Europe has achieved important successes in reducing environmental pressures. In many parts of Europe, the local environment is in a better state than at any point since the start of industrialisation. In addition to improving environmental conditions, environmental policy has delivered clear benefits for human health and well-being, as well as driving innovation and job creation (EEA, 2015).

Despite these achievements, SOER 2015 concluded that Europe faces major environmental challenges if it is to achieve its 2050 vision of 'living well, within the limits of our planet', as defined in the EU's 7th Environment Action Programme (EU, 2013a). These challenges are not about single issues such as reducing air pollution or better nature protection. Instead, Europe's persistent environmental challenges are systemic, in the sense that they are tied in complex ways to prevailing economic, technological and social systems. These interlinkages often make it hard to effect rapid reductions in environmental pressures.

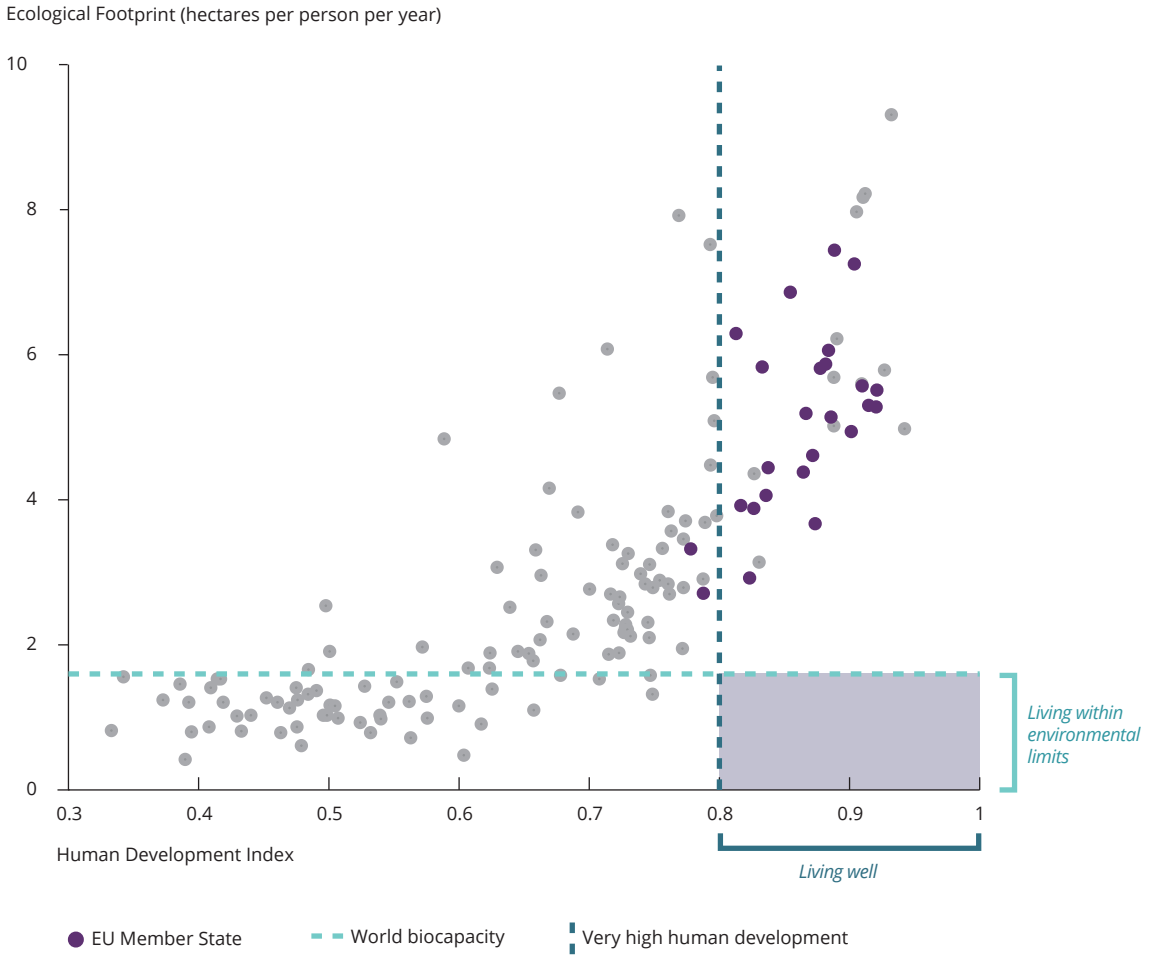
Meanwhile, the 'great acceleration' of economic activity since the industrial revolution has delivered significant improvements in living standards in advanced economies but has also caused growing environmental pressures. As an ever greater proportion of the global population shifts towards the consumption patterns of developed regions, the burden on natural systems threatens to undermine or even reverse advances in living standards (Figure 1.1). For advanced economies in Europe and elsewhere, reconciling high levels or human development (living well) with environmental sustainability (living within environmental limits) is expected to require five-fold ('factor 5') or even ten-fold ('factor 10') improvements in environmental performance (EC, 2011a; UNEP, 2011a).

Against this backdrop, SOER 2015 concluded that Europe must go beyond incremental improvements in environmental performance. Instead, it must find ways to achieve fundamental transitions or transformations in core systems, entailing 'profound changes in dominant institutions, practices, technologies, policies, lifestyles and thinking' (EEA, 2015). These include the consumption-production systems that meet key human needs, such as for food, mobility and energy. But there is also a need for fundamental change in other systems, such as urban, fiscal and financial systems, and the knowledge systems supporting decision-making.

When published, SOER 2015 represented the European Environment Agency's most thorough examination to date of the systemic nature of Europe's environmental challenges. Yet its conclusions were not wholly novel. Rather, they marked a contribution to a broader evolution in understanding of environmental challenges that can be traced back to the 1970s and 1980s. As illustrated in Table 1.1, this has involved a shift away from addressing individual issues based on linear cause-effect principles, towards acknowledging multi-causality and systemic causes. This shift in understanding has been accompanied by an evolution in assessment and policy approaches.

At the European Environment Agency (EEA), the notion of 'systemic challenges' was first taken up in SOER 2010 (EEA, 2010), which identified the need for more integrated approaches to addressing persistent environmental and health problems, and for a transition to a green economy. In 2013, the EEA adopted its Multi-Annual Work Programme (MAWP) 2014-2018, entitled 'Expanding the knowledge base for policy implementation and long-term transitions'. In addition to highlighting the need for 'sustainability transitions', the MAWP focuses one of the EEA's four 'strategic areas' for the period 2014-2018 on 'assessing systemic challenges', with the aim of signalling 'opportunities for (re)framing/recalibrating environmental policy to facilitate transition towards a more sustainable society in Europe'.

Figure 1.1 High living standards are associated with unsustainable environmental pressures



Note: The Human Development Index (HDI) is calculated based on indicators of education, life expectancy at birth and wealth. It is expressed as a value between 0 and 1, from least to most developed countries. HDI scores between 0.8 and 1.0 are categorised as 'high human development'. The Ecological Footprint measures how much land and water area a population requires to produce the resources it consumes and to absorb its waste. The world biocapacity is the global productive area available to produce resources and absorb waste. The HDI and Ecological Footprint data are from 2012.

Table 1.1 Evolving understanding of environmental challenge, policy responses and assessment approaches since the 1970s and 1980s.

Characterisation of key challenges	Key features	In the spotlight in	Policy approaches (examples)	Assessment approaches and tools (examples)
Specific	Linear cause-effect, large (point) sources often local	1970s/1980s (continuing today)	Targeted policies and single-use instruments	Data sets, indicators
Diffuse	Cumulative causes	1980s/1990s (continuing today)	Policy integration and raising public awareness	DPSIR, Data sets, indicators, environmental accounts, outlooks
Systemic	Systemic causes	1990s/2000s (continuing today)	Policy coherence and systematic approaches (e.g. green economy)	DPSIR, STEEP Indicators and accounts, systems analysis, foresight, stakeholder participation

Note: DPSIR denotes 'driver, pressure, state, impact, response'. STEEP denotes 'social, technological, environmental, economic, political'.

Seen against this backdrop, SOER 2015 represented the latest step in an extended knowledge development process. In relation to the EEA's strategic goal of 'assessing systemic challenges', its particular strength was arguably in providing a broad and robust account of Europe's systemic challenges and the need for transitions, based on core environmental indicator frameworks and linking to European Union (EU) policy. However, it provided only limited insights into how transitions occur in practice, and how decision-makers at different scales of governance could catalyse and steer complex processes of systemic change towards long-term sustainability objectives.

Responding to new knowledge needs: the role of this report

Following the publication of SOER 2015 and building towards SOER 2020, the EEA has sought to develop its understanding of transitions and transformations by engaging with relevant research communities and actors and by preparing a variety of exploratory reports addressing a mixture of systems, scales and evidence about transitions (EEA, 2016b, 2016d, 2016c, 2017; EEA-Eionet, 2016; EEA, 2016a). From these interactions and activities, it is evident that diverse academic and policy communities are addressing transitions and transformations, producing a substantial volume of highly relevant analysis. At the same time, these communities remain quite separated, address systemic change through different lenses and across a variety of different types of systems, and employ very different disciplinary perspectives and methods.

As a first step towards making sense of these diverse approaches, the EEA engaged experts from different academic communities to prepare the five papers presented in this report. Three of them provide conceptual frameworks for understanding and informing systemic change:

- 'Transformations in socio-ecological systems' by Karen O'Brien (University of Oslo) and Linda Sygna (cCHANGE), Chapter 2;
- 'Socio-technical transitions to sustainability' by Frank Geels (University of Manchester), Chapter 3;
- 'Socio-economic transformations: insights for sustainability' by René Kemp (Maastricht University), Paul Weaver (Groundswell Research Associates) and colleagues, Chapter 4.

These conceptual frameworks are complemented by two other analytical perspectives:

- 'Action-oriented perspectives on transitions and system innovation' by Fred Steward (University of Westminster), Chapter 5;
- 'Integrated assessment modelling approaches to analysing systemic change' by Detlef van Vuuren and Andries Hof (both Utrecht University), Chapter 6.

To promote insights across the chapters, the authors followed an agreed structure, addressing themes such as conceptual background, understanding of systemic change, empirical examples, governance, strengths and weaknesses, and knowledge.

As such, the overall ambition of this report is to provide an initial analytical overview of framings, conceptualisations and selected analytical tools relating to sustainability transitions and transformations, bringing together insights from multiple academic communities. The report aims to illustrate how these different perspectives relate to each other and to begin to explore what potential guidance they offer for policymaking and governance more broadly. In addition to informing the EEA's knowledge investments towards SOER 2020 and beyond, the report also aims to support the uptake of transitions knowledge more systematically and coherently by experts at the EEA, the Eionet and more broadly.

Focus of this chapter

Section 1.2 provides summaries of the main messages from the five papers presented in Chapters 2-6. The ambition with these summaries is not to capture all aspects of each of the papers, which are very rich and diverse. Rather, they present short and concise overviews of the major themes (e.g. conceptual background, understanding of systemic change, strengths and weaknesses) covered by the authors. The summaries in Section 1.2 provide the basis for reflections on the five perspectives in the subsequent sections.

Section 1.3 compares the five perspectives in terms of their characterisation of what transitions are, why societies need transitions, what systems or structures need to be transformed, and how transitions occur.

Section 1.4 briefly outlines what insights the five papers offer for policy, governance and knowledge development. As the EEA develops its understanding of transitions in coming years, the themes identified are likely to provide a key focus for knowledge development.

1.2 Key messages from the five perspectives

Transformations in socio-ecological systems

As explained by O'Brien and Sygna, socio-ecological systems are defined in different ways but share a common understanding of being systems 'characterised by interconnections, mutual dependencies and dynamic relationships between humans and the environment'. Analysis of transformations in socio-ecological systems combines elements from both the natural sciences and the social sciences, reflecting a 'growing recognition of the importance of integrating biogeophysical, social and human dimensions in analyses of sustainability at all scales'. For the time being, however, this integration remains partial, with the natural and social scientific perspectives offering contrasting focuses.

Earth system science tends to focus primarily on 'descriptive and analytical' assessment of 'observed and projected transformations of global systems in response to human activities'. It emphasises the dynamics of natural systems and associated risks, in particular the notion that exceeding 'planetary boundaries' or other 'tipping points' risks causing abrupt and irreversible environmental change, with serious implications for human security and well-being. Evidence about the environmental effects of escalating human activity in recent centuries (the 'great acceleration') points to the need for urgent action to reduce pressures on ecosystems.

In contrast, social science contributions focus more on 'deliberate transformations to sustainability through social change'. From this perspective, socio-ecological transformation comprises 'a process of altering the fundamental attributes of a system, including structures and institutions, infrastructures, regulatory systems and financial regimes, as well as attitudes and practices, lifestyles, policies and power relations' with the aim of tackling sustainability challenges. Failing to acknowledge the roles of power, politics and interests can lead to the prioritisation of techno-managerial approaches, rather than more transformative alternatives.

In general, research into deliberate socio-ecological transformations is '**solutions oriented**, seeking to engage with society through post-normal science or action research that is co-designed and co-produced with society'. In keeping with the strong emphasis on transdisciplinarity, research into transformation brings together the work of a diverse mixture of scientific communities, addressing fields such as resilience, social practices, social studies of science and technology, Earth system governance, behavioural psychology and communication.

This willingness to draw on the insights from a mixture of disciplines is apparent in the three analytical approaches to transformations discussed by O'Brien and Sygna. Specifically, these are:

- **Resilience** approaches to transformations, which draw heavily on ecological understandings of system dynamics. The discussion highlights in particular Holling and Gunderson's concept of the 'adaptive cycle', which suggests that socio-ecological systems are often characterised by cycles of disruption and reorganisation (Gunderson and Holling, 2002).

- **Pathways** approaches map out alternative strategies or development trajectories to meet visions and goals, recognising that there are multiple ways of meeting these goals, while also acknowledging uncertainty and complexity. Such pathways expose not only potential implications for environmental change but also themes such as equity, justice and sustainability. This approach is further operationalised by integrated assessment modelling methods outlined in Chapter 6.

- The **spheres of transformations** approach, which highlights three key domains for effecting transformations in socio-ecological systems — the practical, political and personal. The approach recognises role of actors and the value of experimentation in achieving transformations. It emphasises the fundamental importance of the personal domain (e.g. changing values and worldviews) in ways that resonate with the socio-economic perspective presented in Chapter 4.

These three analytical approaches share an understanding that deliberate transformations of socio-ecological systems are complex, uncertain and emergent processes, combining actions and change at multiple scales. O'Brien and Sygna draw attention to several other common themes, such as disruptive and unexpected events, in particular the potential for crises or extreme events to accelerate systemic change; the role of leaders; and the importance of transforming mindsets and worldviews.

In contrast to the macro-scale focus of global environmental change research, much research into deliberate socio-ecological transformations appears largely place-based, addressing human-nature interactions in local settings. Moreover, despite including insights from socio-technical transitions research, the focus is often on natural resources and

ecosystems, targeting human behaviours and values rather than technological innovation in systems such as energy and mobility. The empirical examples in the chapter exemplify this focus, addressing the food-water-energy nexus, climate smart agriculture and permaculture at the local scale.

In terms of governance, socio-ecological research again embraces a mixture of approaches, partly reflecting the different scales that are being addressed. The global challenges identified by Earth system science (e.g. climate change) are often understood to be collective action problems necessitating coordinated global responses based on negotiations, targets and monitoring. At the same time, the complexity and uncertainty of the dynamics of socio-ecological systems are reflected in calls for learning and adaptive governance. And the focus of much socio-ecological analysis on local scales points to the need for 'polycentric' modes of governance.

O'Brien and Sygna argue that the strength of socio-ecological research lies in providing a 'big picture, systems perspective that integrates humans with nature', and illustrating where sustainability solutions may lead to unintended environmental and social consequences. They suggest that socio-ecological analysis is weaker in explaining how systemic change can be achieved. For example, it lacks a framework linking individual actions to system outcomes and overlooks important lock-ins and trade-offs. Perhaps most fundamentally, socio-ecological transformations research still struggles to integrate its natural and social science dimensions.

Socio-technical transitions to sustainability

As explained by Geels, socio-technical analysis addresses stability and change in the systems that perform core functions for society (e.g. providing energy, mobility, housing) but also account for most of humanity's pressures on the environment. Drawing on a mixture of disciplines — in particular, evolutionary economics, innovation studies and institutional theory — socio-technical research provides insights into the barriers and opportunities that societies face in achieving systemic change.

Socio-technical systems are understood to be complex, multifunctional systems combining diverse elements, which evolve interdependently. This process of co-evolution can make them resistant to fundamental and far-reaching change. For example, the emergence of the car as the dominant form of land-based transport was accompanied by major private investments in skills, knowledge and infrastructure for car production; public investments in road infrastructure; emergence of complementary industries to manufacture and deliver fuel, tyres and other accessories; adaptation of urban design to the car; and changes in behaviour, expectations and cultural values linked to car ownership.

The interdependence of these diverse elements means that there are often strong economic, social and psychological incentives favouring incremental efficiency improvements to established socio-technical systems over more radical systemic change. From a sustainability perspective, this sluggishness appears problematic because addressing persistent environmental problems requires urgent and far-reaching systemic change in societal systems. At the same time, research into the dynamics of socio-technical systems suggests some cause for optimism. This is because historical case studies indicate that change in socio-technical systems follows a 'punctuated equilibrium' path, implying long periods of stability and incremental change interspersed with relatively short and sudden periods of disruption and 'waves of creative destruction' (i.e. transitions). The challenge for analysis of sustainability transitions is therefore to determine how societies can initiate and steer such processes of systemic reconfiguration towards long-term environmental and socio-economic goals.

Within socio-technical research, the multi-level perspective (MLP) has emerged as the dominant analytical framework for understanding transitions. The MLP explains the dynamics of transition processes as arising from the interplay of developments at three analytical levels: regime, niche and landscape. The socio-technical regime comprises the diverse established elements outlined above, such as existing technologies, regulations, user patterns, infrastructures and cultural discourses. Innovative new technologies are seen as playing an essential role in catalysing systemic change at the regime level. Yet they often struggle to have any impact because of the diverse economic, social and political lock-ins to established modes of production and consumption. According to the MLP, for innovations to emerge and alter the dominant system additional aspects are needed. The first is 'niches': protected spaces, such as research and development laboratories, where innovators can develop, nurture and experiment without direct exposure to market forces, consumer preferences and so on. The second is landscape-level developments, such as escalating global resource scarcity or a nuclear accident, which can disrupt the regime. This destabilisation of the dominant regime can create a window of opportunity for a novel, niche innovations to establish themselves.

As described in the MLP (and the various theories that inform it), transitions involve the co-evolution of technological innovations and social behaviours, and emerge through interactions among multiple actors, including businesses, users, scientific communities, policymakers, social movements and interest groups. Transitions are long-term processes, typically spanning 40-50 years. Being evolutionary also means that they are open ended, non-linear, fundamentally uncertain, and based on searching, learning, trial and error, and experimentation. Surprises and unintended outcomes are likely. Such transitions depend critically on interpretations and social acceptance. They are also conflictual and deeply political, producing trade-offs, 'winners and losers', and related struggles, as politically influential and well-resourced incumbents often resist change.

Collectively, these characteristics imply major challenges for efforts to achieve sustainability transitions. The logic of the MLP suggests that policymakers and other actors can support transitions by creating niches that foster experimentation and innovation (e.g. via state funding for research and development); supporting upscaling (e.g. by subsidising adoption); and facilitating regime reconfiguration (e.g. by regulating or taxing dominant environmentally harmful technologies or by compensating or retraining workers). Recognising that there will be winners and losers with all choices, participatory processes involving envisioning and goal setting can also help in setting the direction for systemic change by giving the space for dialogue between the actors. This points to the need for sophisticated policy mixes that are coordinated across domains and scales of government. Even if this is achieved, the hugely uncertain social and environmental implications of socio-technical change point to the need for adaptive governance styles, with regular monitoring and feedback into policy design.

Geels argues that an important strength of socio-technical analysis is in bridging different themes and scales of analysis. The MLP, in particular, provides a logical framework that links local scale activities to systemic change and broader macro-level framings and paradigms. Socio-technical research also highlights the role of different kinds of agency and associated barriers (e.g. in terms of conflict, power struggles and trade-offs), as well as the complexity and uncertainty of transitions. In directing attention towards the opportunities and barriers to changing the production-consumption systems driving environmental degradation, socio-technical analysis points to the kinds of policies that could help steer transition processes, in particular in relation to technology-intensive sectors such as energy and transport.

Geels notes that socio-technical analysis is weaker in explaining change in less technology-intensive sectors, such as the food and water systems. The dominance of qualitative, case study-based evidence in socio-technical research also makes it hard to extract broader rules that are uniformly applicable across different contexts. Moreover, its focus on processes rather than sustainability impacts means that the MLP provides limited insights into the extent to which environmental (or socio-economic) problems will be alleviated through such transitions.

Socio-economic transformations: insights for sustainability

Kemp et al. address socio-economic transformations from two perspectives. Their primary focus is on market capitalism as the dominant socio-economic paradigm across the world. Building on the foundational work of Polanyi on societal transformations, the chapter describes the market's role in shaping human identity, values and behaviours, in particular the 'marketisation of society' that followed the industrial revolution. It goes on to explore the potential for social innovation to trigger change towards more socially and environmentally beneficial economic structures. As a secondary focus, Kemp et al. address important economic sub-systems, such as the fiscal and financial systems, which have a major influence on the configuration and dynamics of society's systems of production and consumption, but are subject to their own lock-ins and barriers to change.

As explained by Kemp et al., socio-economic transformation is not a single field of study but a topic studied by people in multiple disciplines, including political economy, sociology, political philosophy, psychology, economics and nature-society relations. These perspectives share a perception that current global market structures and norms are key drivers behind many of society's sustainability challenges, including 'environmental degradation, hedonism, economic insecurity, social exclusion and the loss of social bonds'.

According to Kemp et al., the influence of the market economy plays out in different ways and at various scales. Individuals are locked into a cycle of 'work and spend' by consumption competition and labour market rigidities that prevent people working shorter hours. Consumerism and materialism is making people unhappy rather than increasing utility. Market failures result in mispricing of ecological resources, driving environmental degradation. Commonly used indicators of economic performance and social progress, such as earnings and gross domestic product (GDP), provide

misleading signals about trends in well-being and quality of life — overemphasising material wants and underrepresenting immaterial goods such as freedom of choice and autonomy. Yet governments are locked-in to the economic growth paradigm that is known to be socially and environmentally harmful, partly because of the need to maintain employment levels and finance the welfare state.

Drawing on thinkers such as Polanyi, Tilly, and Freeman and Louçã, who have analysed socio-economic change over long time-spans, Kemp et al. describe socio-economic transformations as co-evolutionary processes that include changes in modes of production, work relations and culture. Although technological innovation has played a key role in the marketisation of society, the authors question the potential for technologies alone to enable transformations to sustainability. As they note, in lowering prices, efficiency gains often lead to increased consumption, undermining environmental benefits and arguably reinforcing the dominant paradigm of consumerism and materialism.

The discussion therefore focuses more directly on changes in values and lifestyles, and on the formal and informal institutions that shape individual behaviour. Social innovations are identified as having a key role in enabling transformations to alternative economic forms, founded on humanistic and communitarian principles. Examples of such innovations include 'collective forms of living and work, local resilience initiatives (such as transition towns and urban gardens), commons-based forms of production (co-maker spaces and peer-production), practices of permaculture and slow food'.

Activities such as these could offer direct environmental benefits, particularly if upscaled. But the authors suggest that the benefits to well-being could also be more indirect, for example by 'averting consumerism and helping spread an alternative vision of a good life'. Moreover, creating alternative economies that meet society's material and immaterial needs could potentially also weaken the growth paradigm by alleviating the need for politicians to prioritise job creation and tax revenues. This would enable them to focus more on environmental protection and social goals.

Alongside bottom-up activities aimed at creating alternative economies, the chapter also highlights opportunities and barriers for state action to correct market failure. Ecological fiscal reform has long been identified as a means to reduce resource demand and pollution, while also enabling reductions in taxes on earnings, although research suggests that the scope for increasing environmental tax revenues may be somewhat limited. Financial market reforms aimed at reducing systemic risk and redirecting investments towards environmentally and socially desirable activities are essential. But social and technological innovations, such as the emergence of crowdfunding platforms, also offer means to pool funding for socially desirable investments.

Turning to the issue of governance, Kemp et al. argue that the multi-scalar, long-term and complex character of socio-economic transformations necessitates society-wide engagement in governance and adaptive governance approaches. Nevertheless, governments retain a critical role in creating a framework for such engagement and have a unique role in organising and regulating markets and correcting market failures. Green growth strategies can bring together the different public policy interventions that could support systemic change, including public investment in research and development, tax subsidies and demand-side policies. Alongside state actions, Kemp et al. highlight Ostrom's work on governance of the commons, as well as other approaches, such as adaptive governance and grassroots activities, aimed at creating alternative economies. Financial reform is also needed to reorient investment towards mitigating or adapting to emerging sustainability problems. This issue is seen as crucial but complex for both policymakers and wider governance structures.

Kemp et al. argue that a major strength of the socio-economic perspective is its direct focus on the dominant economic paradigm and its role in shaping the values and mindsets that ultimately drive unsatisfying and unsustainable lifestyles. While stressing the constraints on government powers, they argue that the state has opportunities to enable socio-economic transformation, both via policy interventions and by creating space for the emergence of alternatives economies founded on less materialistic sources of well-being. At the same time, Kemp et al. acknowledge that research into transformation of this sort is limited and fragmented, lacking a framework for understanding the importance and impact of alternative economies. Much more research is needed to address these issues.

Action-oriented perspectives on transitions and system innovation

Rather than addressing particular societal systems, Steward's discussion of action-oriented perspectives focuses on the role of three groups of actors that seek to influence transitions: community-based non-governmental organisations; city-level authorities; and trade unions.

Research and policy increasingly recognise the importance of bottom-up actions in responding to environmental challenges, including global collective action problems such as climate change. For example, Elinor Ostrom's work highlights the capacity of communities to manage the environmental commons at local scales, as well as the potential for 'polycentric' systems of communities to tackle global issues, through cumulative, cooperative or (state) coordinated actions. The research communities addressing socio-ecological, socio-technical and socio-economic transformations likewise emphasise the need to engage a diverse mixture of actors at multiple scales. These characteristics point to the importance of combining top-down policy with more distributed market and network forms of governance.

The 'bottom up' framing of sustainability challenges and responses is increasingly represented in global sustainability policy. For example, the Paris Agreement (under the United Nations Framework Convention on Climate Change) includes provisions welcoming the efforts of 'civil society, the private sector, financial institutions, cities and other subnational authorities' in addressing and responding to climate change.

In assessing each of the three groups of actors (communities, cities, trade unions), Steward first presents examples of relevant initiatives and then discusses academic analysis of these activities.

At the community scale, Steward describes five organisations that link together community-level initiatives into networks, with the aim of achieving systemic and transformative change: the Transition Network, the Global Ecovillage Network, Community Power, the Open Food Network and The Food Assembly. According to Steward, the academic literature provides strong justifications for analysing transitions through a focus on communities. One important strand of research is social practice theory, which focuses on groups rather than on individuals. According to this approach, new social practices emerge continually through the interaction of actions, materials, competencies and meanings. This insight suggests that policy measures may have only limited impact in terms of changing social practices. However, 'it also shows "that social change happens all the time" and that it is possible to intervene by "guiding the direction of such change, and being sensitive to the inadvertent effects of policy which might lock-in or even encourage resource-intensive ways of life" (Spurling et al., 2013).

Other researchers have explored the role of communities and social movements in the multi-level perspective on transitions. They contend that community activities can play an important role at all levels, for example by creating niches for innovation, disrupting incumbent regimes and transforming cultural values.

Nevertheless, academic assessment of community initiatives is not wholly positive. Some researchers (Chatterton and Cutler, 2008) question the capacity for local initiatives to achieve systemic change at the scale needed to address global sustainability challenges. The emphasis on creating strong, highly engaged community groups may make it hard to also achieve broad involvement. This may be inconsistent with the goal of self-sufficiency and it also raises questions about whether such groups are representative of the larger community that they aim to change.

Turning to city-led initiatives, Steward notes that sustainability-oriented actions by cities and regions have proliferated in the last two decades. Indeed, the emergence of international networks of cities addressing sustainability and climate change arguably represents 'a new mode of transnational network governance'. The Global Covenant of Mayors for Energy and Climate Change exemplifies this trend, bringing together more than 7 100 cities from 119 countries with a total population of 600 million. Local Governments for Sustainability (ICLEI) and the C40 Cities Climate Leadership group are also discussed.

Academic analysis focuses on the distinctive contribution that cities can make to transitions. For example, cities provide niches for experimentation, learning and upscaling, partly because they are increasingly embedded in networks at national and global scales. Moreover, regime change at the city scale may be easier to achieve than at broader scales because of the advantage of proximity for creating actor networks, as well as the often substantial governance capabilities at the city level.

The third group, trade unions, have engaged with the transitions concept in Europe since the early-2000s, focusing in particular on the social impacts of regime change. The concept of the 'just transition' was embraced by the European Trade Union Confederation in 2009 and featured in the Paris Agreement on Climate Change in 2016 — the only reference to 'transition' in that agreement. It encompasses a focus on sustainable industrial policy, a robust social 'safety net' and wide-reaching labour adjustment programmes. However, alongside this 'reactive' position focused on minimising harms, there is also some evidence that trade unions are engaging more proactively with transition processes as unique opportunities to combine environmental, social and economic benefits.

The community, city and trade union initiatives reviewed, such as the Transitions Network and the Global Covenant of Mayors appear to fulfil a new role in governance, distinct from either government policy or market forces, but consistent with the emerging 'platform of actions' approach promoted by the Paris Agreement, which enable non-state actors to link and share data and practices. The 'platform of actions' approach appears to differ from the conventional dualistic discourses of national government policy and market forces, or economy and individual.

In terms of governance approaches, Steward notes that the diverse mixture of different actor groups that he has reviewed appear to share 'an active interest in a set of new and participative governance practices'.

In particular, four broad competencies appear frequently in the action-oriented domains reviewed:

- **visioning**, using scenarios, roadmapping and backcasting to identify potential routes from the present to a desired future, and to inspire and motivate action;
- **experimenting** or 'learning by doing' in conditions of ambiguity — increasingly in the form of 'living laboratories' in urban settings;
- **networking**, often via 'communities of practice' or the creation of a 'transitions arena';
- **navigating** (rather than controlling) complex processes of systemic change.

Steward argues that the strengths of the action-oriented approach include the emphasis on the agency and potential influence of non-state actors, which is seldom acknowledged sufficiently. The approach also recognises the existence and value of non-academic knowledge 'arising from sense-making and discursive practices'.

On the other hand, Steward also notes that the action-oriented approach can provide an 'uncritical and over-optimistic view of the role of non-state actors'. The emphasis on place-based analysis also has the unfortunate consequence of ignoring alternative framings such as value chains or innovation networks. Furthermore, the desirable prominence of network governance approaches is accompanied by a weak connection with formal governance structures, which are sometimes perceived to be opponents rather than potential allies.

Integrated assessment modelling approaches to analysing systemic change

Integrated assessment modelling offers a quantitative analytical approach to understanding systemic change, which contrasts with and complements the conceptual frameworks on socio-ecological, socio-technical and socio-technical transitions discussed above.

As explained by van Vuuren and Hof, the overall aim of integrated assessment modelling approaches is to support policymaking, and society more broadly, with model-based quantitative scenarios about potential trajectories of change necessary to meet environmental, climate and social targets. Targets addressed typically have a long-term future perspective with a time horizon to 2050 or 2100, such as international targets relating to climate change or halting global (or regional) biodiversity loss. Modelling trajectories of change towards such targets requires an understanding of the complex interactions and relationships between biophysical systems (climate, ecosystems, global water and nutrient cycles, etc.) and key features of socio-economic systems, such as economic, technological or population changes. These interactions are captured in mathematical models referred to as 'integrated assessment models' (IAMs).

Integrated assessment modelling mainly draws upon concepts and theories from macroeconomics, engineering, Earth system science, and environmental sciences more broadly. Common to these disciplines is an orientation towards quantitative analytical tools and assessment methods. Accordingly, IAMs aim to quantify human-environment relationships and interactions, most typically based on macro-economic assumptions about cost factors, cost optimisation and carbon pricing. This means that in the model all variables and their interrelationships (e.g. assumptions about population change, carbon prices, the development of energy technologies) are converted into mathematical equations that describe (changes in) economic costs.

As explained by van Vuuren and Hof, factors that are more difficult to capture in mathematical equations, such as assumptions about individual human behaviour and interactions between actors, interest groups, institutional changes, political changes, or governance more broadly are only stylised in most models. Such a stylised (and thus limited) representation in the models is typically implemented by introducing alternative or additional costs.

Due to the mathematical structure and economic orientation towards cost minimisation, IAMs conceptualise systemic large-scale change as a smooth and goal-oriented process, without major

or abrupt shocks, tipping points or any other kind of non-linear system behaviour. Change is modelled as an emergent property. For example, the changes in technology application over time result from changes and interactions of input variables (population, technological development, etc.). Barriers to change are accounted for explicitly or implicitly, through assumptions about technical factors (e.g. inertia, technical requirements), economic factors (e.g. changes in carbon price) and social factors (e.g. consumer preferences), which are again translated into mathematical functions of economic costs.

Results of integrated assessment modelling approaches are usually quantitative projections about trends in greenhouse gas emissions, energy mixes, land use shares, or biodiversity, often at very aggregated levels. In many cases multiple, alternative scenarios are modelled. Most often the models produce a 'baseline' scenario that assumes a continuation of current policies, alongside a range of 'normative scenarios' in which pathways towards specific targets or alternative policy goals are modelled. The latter type of scenarios focus on the action required, as well as the costs and benefits of achieving these targets. For example, IAMs can model potential energy, land use and emissions trajectories for the five socio-economic scenarios currently employed by the Intergovernmental Panel on Climate Change (IPCC). In doing so, IAMs can, for example, shed light on possible energy shares (for coal, gas, biomass, solar, wind, etc.) at different points in time in the future under different socio-economic assumptions. IAMs can also provide insights into the effects of delaying climate mitigation action, or can be used to assess the importance of different technologies for achieving long-term climate or biodiversity targets.

For these reasons, van Vuuren and Hof argue that IAMs are highly suitable for exploring key long-term dynamics in human-environment interactions and for highlighting potential trade-offs across multiple competing policy visions and ambitions. Quantitative IAM outputs provide policymakers with tangible indications of how policy objectives relate to associated physical changes (emissions, climate, land, biodiversity, etc.), and about potential quantitative effects of different policy options. As a result, van Vuuren and Hof argue, IAM results have been influential in informing high-level policymaking, for example in an agenda-setting role and for establishing long-term targets.

Van Vuuren and Hof also point out, however, that the attractiveness of IAM outputs can also be a weakness, if their quantitative results are interpreted as hard-wired predictions about the future without giving sufficient attention to associated uncertainties and limitations.

In addition, IAMs typically conceptualise systems as collections of technologies and their interactions, and tend to marginalise or neglect a variety of important aspects, which may be important for policymaking. These include alternative forms of innovation (e.g. organisational, social or business model); the institutional and cultural context of social and technological innovation; power and vested interests; and the non-linearity of real world processes. As a result, IAMs may overemphasise the potential for economic instruments to achieve policy goals, and downplay problems arising from strategic behaviour, resistance from incumbents, and constraints on policymakers.

1.3 Reflections on the five perspectives

The five perspectives presented in this report provide a diverse mixture of insights into the sustainability challenges faced in Europe and globally, as well as possible responses. While it seems unlikely that these different perspectives can be integrated into a single framework, **they do appear to share certain characteristics and complement each other in useful ways**. As Steward notes, however, we currently lack a 'meta framework using a set of shared concepts within which these different systemic approaches can be positioned'. As he points out, the aim of such a framework would not be to 'impose unrealistic integration but to encourage a common discourse'.

The brief reflections that follow provide steps towards such a common discourse, highlighting key themes and questions, and exploring how the five perspectives relate to each other. For example, this section addresses what transitions are and why we need them; which systems need to be transformed; how transitions are understood to occur; and the implications for governance and knowledge. The reflections are based on the five papers but expand on some issues using other sources to help illustrate and explain the key ideas.

1.3.1 What are transitions and why does society need them?

The perspectives presented in this report share a recognition that achieving European and global sustainability goals will require large-scale and fundamental changes to the societal systems driving environmental pressures. On closer examination, however, the papers suggest rather different framings of the issues, particularly regarding what transitions are and why they are needed.

On the issue of what transitions are, van Vuuren and Hof's paper on integrated assessment modelling presents a fairly 'mainstream' characterisation of transitions, which defines them in terms of the scale and urgency of needed changes. In contrast, the socio-ecological, socio-technical and socio-economic papers appear to share a more specific understanding of transitions as involving abrupt, non-linear and disruptive changes in complex systems.

Regarding why we need transitions, the socio-ecological perspective introduces the notion of planetary boundaries, whereas the socio-economic perspective emphasises the social failings of current systems and structures. The other perspectives arguably lack a comparable normative element and instead orient themselves to varying degrees towards these two goals: respecting planetary boundaries and securing social foundations.

This section will look into these different framings in a bit more detail. It will start by setting out very briefly some of the key concepts from resilience and systems theory, which are particularly associated with the socio-ecological perspective. These provide a useful foundation for understanding the contrasting understandings of transitions presented in this report.

Systemic understandings of transitions: resilience and regime change

As explained by Scheffer (2009), systems theory is grounded in an understanding that, due to the co-evolution and interaction of system elements, **complex systems such as ecosystems tend to settle in stable states**. As illustrated in Box 1.1, a system will tend to gravitate back to its stable state after a shock, unless the disturbance is so large that it causes a 'regime shift' or 'transition' to an alternative equilibrium. As a consequence, when systemic change does occur, it tends to take the form of abrupt and radical shifts, rather than being gradual, predictable and reversible.

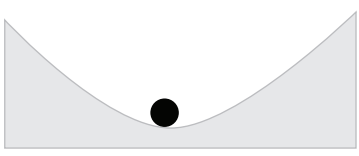
According to this understanding of system dynamics, a system's resilience can be understood as the magnitude of disturbance that the system can tolerate without undergoing a shift to a new stable state (Holling, 1973).

When focusing on the major natural systems that sustain humanity, socio-ecological thinking emphasises the need to maximise resilience. This is the logic underpinning the 'planetary boundaries' framework, which contends that changes in key variables, such as pollution, nutrient flows or climate change, can reduce the resilience of ecosystems, increasing the risk of irreversible and abrupt environmental change (Figure 1.2).

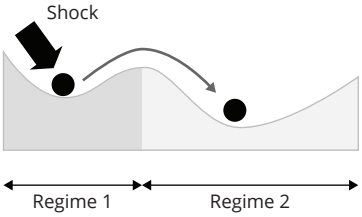
At the same time, socio-ecological research also acknowledges that some complex systems are actually causing environmentally and socially undesirable outcomes. In these situations, system resilience actually represents a problem. As Holling and Walker (2003) note, 'Resilience, per se, is not necessarily a good thing. Undesirable system configurations (e.g. Stalin's regime, collapsed fish stocks) can be very resilient. … Building resilience of a desired system configuration requires increasing the adaptive capacity of structures and processes (social, ecological, economic) that

Box 1.1 Stability landscapes

Graphically, the concepts of system stability, regime shifts and resilience are often presented using 'stability landscapes'. These convey the idea that a system (the ball) will tend towards and equilibrium state or 'attractor' (the bottom of the basin).



A sufficiently large shock can cause a shift to an alternative stable state. Graphically, a system's resilience can be understood as the size of the basin in which it is located. A very resilient system will sit in a large basin.



Resilience may change due to external factors. Such changes may increase or reduce the size of disturbance needed to cause a transition to a new regime, even to the point where systemic change is inevitable.

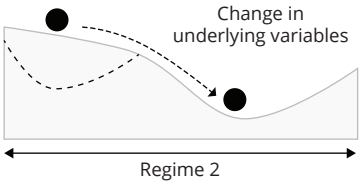
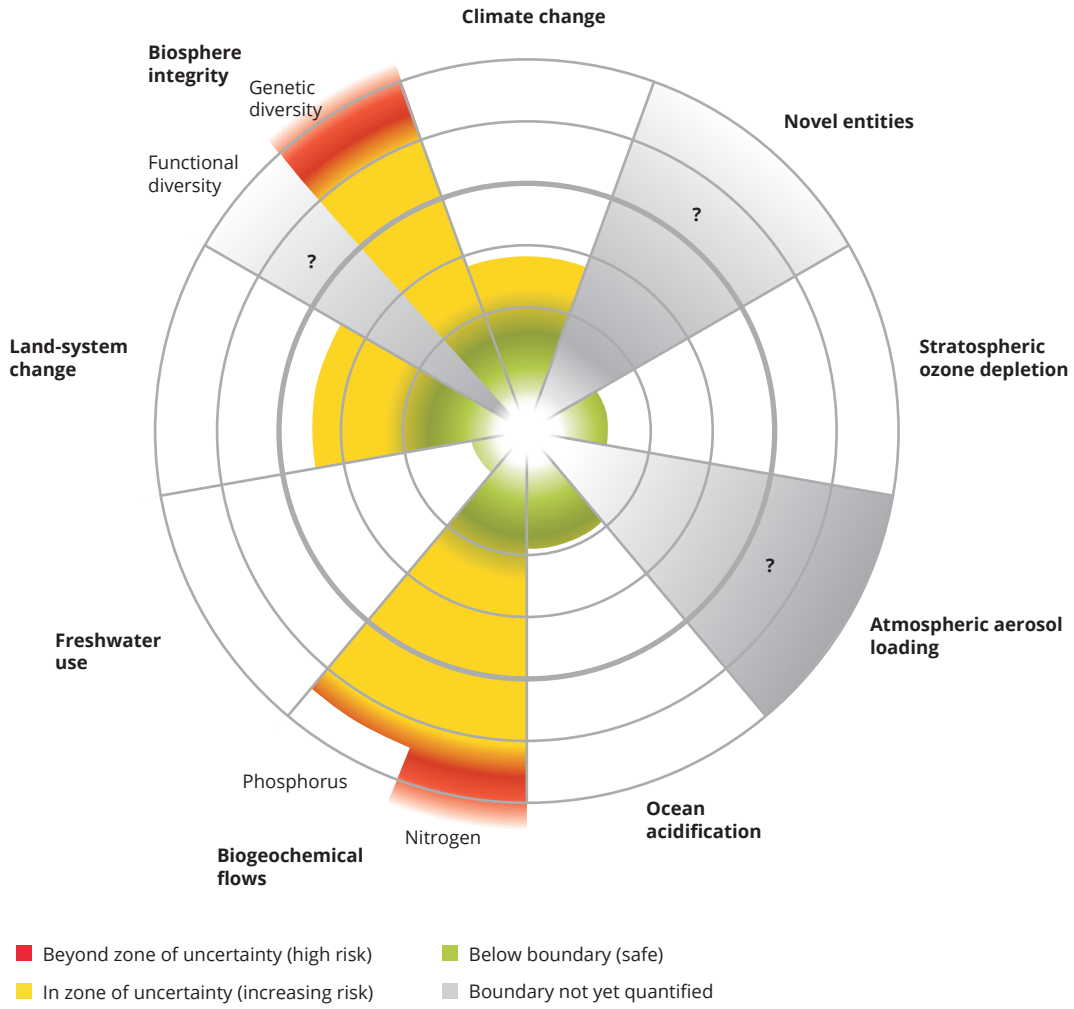


Figure 1.2 The planetary boundaries framework



Source: Steffen et al., 2015a.

help maintain this configuration. It also requires reducing the adaptive capacity of those that tend to undermine it.'

Put another way, **preserving the resilience of desirable systems (such as the ecosystems that sustain humanity) will depend in part** on overcoming **the resilience of harmful systems** (such as the consumption-production systems driving environmental degradation). On this basis, resilience researchers argue that 'transformability' is an integral part of the broader concept of resilience (Walker et al., 2004; Folke et al., 2010).

Why are transitions needed?

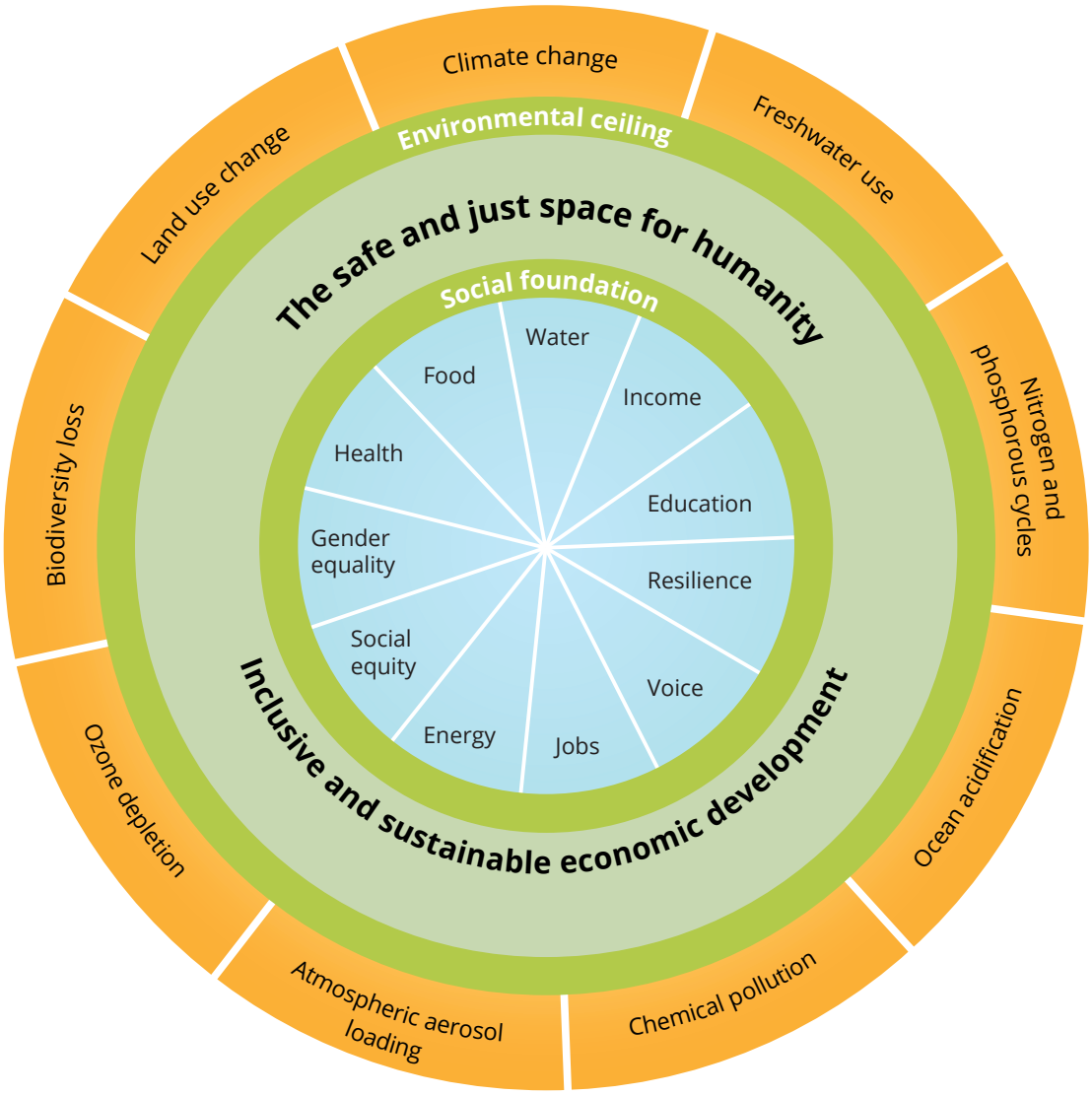
The concepts of resilience and regime change in complex systems features prominently in socio-ecological research, providing a basis for calls for sustainability transformations in environmentally harmful subsystems. Yet the notion of **environmental boundaries and associated risks of sudden and catastrophic change** also appears in the other four papers as a core rationale explaining why societies need to achieve systemic change. The socio-technical and integrated assessment modelling perspectives, in particular, adopt the environmental boundaries

and related global policy targets as their underlying constraints. As such, their focus is on understanding how systemic change occurs and its implications, rather than on identifying social or environmental end points.

The socio-economic perspective likewise emphasises the importance of environmental boundaries but it also highlights a variety of **social problems arising from the prevailing market capitalist socio-economic system** (e.g. materialism, consumerism, commodification, alienation) as factors necessitating transformations in the dominant paradigm. In this sense, the socio-economic perspective complements the socio-ecological perspective's focus on environmental boundaries with an attention to the 'social foundations' for sustainability (Figure 1.3).

While this social justification for transformations is less prominent in the other perspectives than the environmental rationale, it does appear in some places. For example, Steward highlights that trade unions increasingly engage with transitions in a proactive way that aims to address the socio-economic failings of existing production systems.

Figure 1.3 The environmental ceiling and social foundations for sustainability



Source: Based on Raworth, 2012.

What are transitions?

The natural science framing of stability and change in complex systems also seems to have wider relevance across the different perspectives in explaining what transitions are. In particular, the **socio-technical and socio-economic frameworks appear to be grounded in very similar understandings of the barriers to change and the characteristics of transitions**.

Socio-technical research illustrates this point particularly clearly, even adopting some of the language of ecology to explain system dynamics. As captured in the MLP, the co-evolution of technologies, institutions, behaviours, rules and values produces a socio-technical 'regime', which is locked into a 'dynamic equilibrium' and is therefore resistant to transition to a fundamentally different form. When it occurs, **systemic change follows a 'punctuated equilibrium' dynamic** (another concept from evolutionary biology), with 'long periods of relative stability ... punctuated by brief periods of disruption and overthrow'. Although the factors that produce lock-ins in socio-technical systems, such as long-term investments and infrastructure, jobs and earnings, social norms and rebound effects, are rather different from those that influence ecological systems, the basic mechanisms of interactions and feedbacks are broadly equivalent.

In relation to socio-economic systems, Kemp et al. likewise identify a diverse mixture of factors that make unsustainable systems resistant to change, ranging from political incentives, path dependency, vested interests and psychological factors to the globalisation of economic and financial markets. They say less about the dynamics of socio-economic transformations, yet in giving prominence to the work of thinkers such as Freeman and Louçã (2001) and Perez (2003) on techno-economic paradigms and revolutions, they implicitly seem to share an understanding that **societal systems may be characterised by long stable periods, punctuated by relatively abrupt periods of change**. Like O'Brien and Sygna, they also emphasise the fundamental role of paradigms and worldviews, which can create major constraints to systemic change but also have the capacity to trigger large-scale transformations. Finally, in explaining barriers to transformations they highlight the importance of policy 'regimes' — combinations of power arrangements, policy paradigms, state institutions and instruments that collectively produce policy lock-ins.

In summary, despite having very different disciplinary foundations and systemic focuses, the three systemic frameworks and also Steward's action-oriented perspective appear to share an understanding of the properties and dynamics of complex systems (Figure 1.4). Furthermore, this understanding has much in common with the ecological resilience perspective outlined in Box 1.1. Whether these similarities with mathematical systems theory are merely metaphorical or provide evidence to support a 'unified theory of complex systems' is unclear (Horgan, 1995; Geels, 2010). Some researchers have cautioned against applying ecological concepts, such as resilience, in the social domain (Olsson et al., 2015). What is clear, however, is that **this broadly shared characterisation of systemic change contrasts significantly with more mainstream analytical approaches, as exemplified by the integrated assessment modelling paper**.

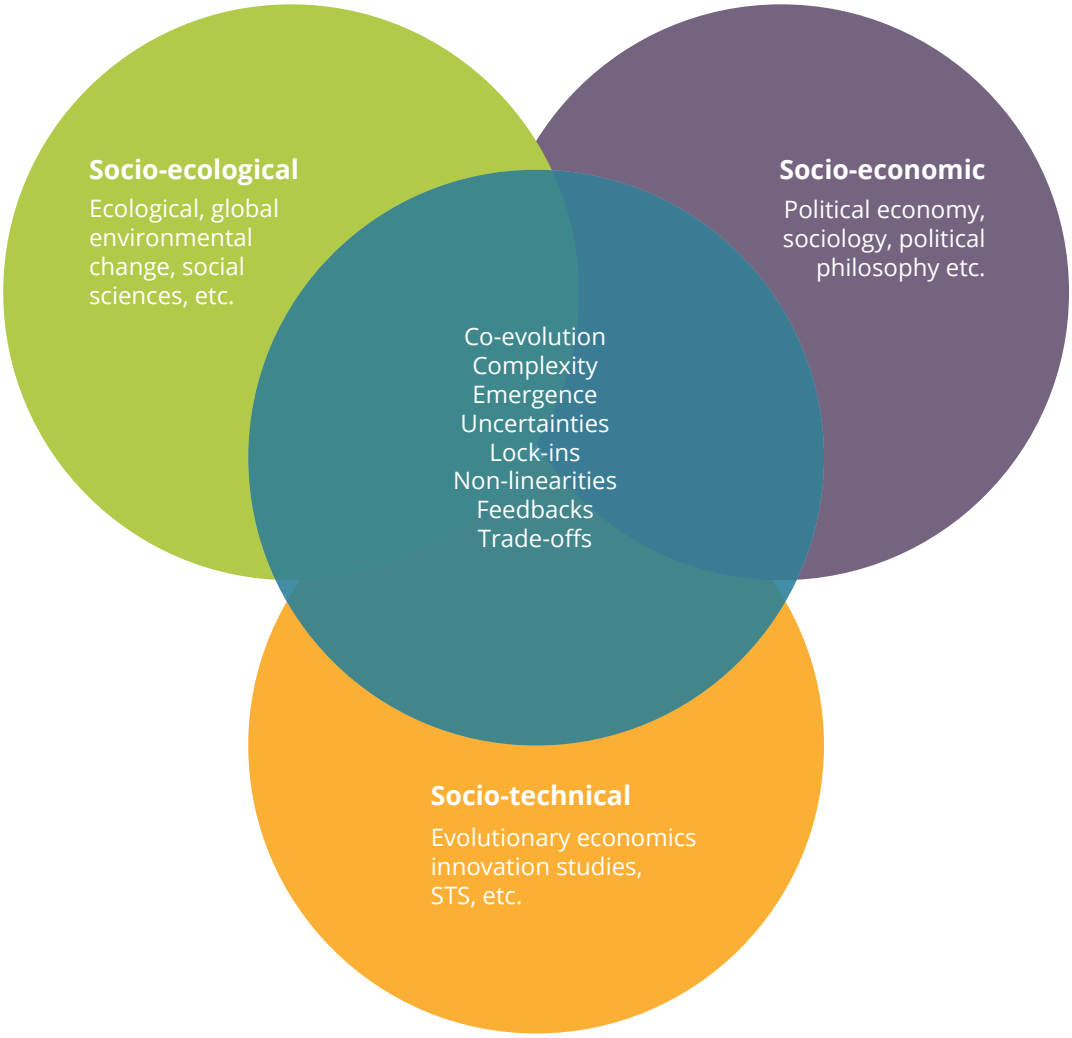
As discussed by van Vuuren and Hof, integrated assessment modelling provides a very different perspective of system stability and change that is not centred around the concepts of resilience and lock-ins. Instead, **IAMs conceptualise transitions as largely smooth and gradual processes steered by economic incentives** (cost optimisation, greenhouse gas cost abatement curves, etc.). Thus, IAMs mostly work on the assumption of an 'ideal world' that tends to downplay issues such as sudden shocks or resistance to change due to powerful political, social and business interests. As will be discussed, these contrasting understandings of the sustainability challenges facing society — the 'mainstream' and the 'systemic' — may point towards different types of governance response.

1.3.2 What needs to be transformed?

The five perspectives presented in this report share an understanding that the stability of global ecosystems will require transitions or transformations of different types of societal systems. Turning to the question of what exactly needs to be transformed, however, there are some significant differences both between and within the five perspectives. This variation is evident in terms of the types of system or structures that are addressed, as well as their scales, which range from local communities and locations up to the dominant global socio-economic paradigm.

In some instances, for example in socio-ecological research, there is a certain amount of **ambiguity about what systems or parts of systems actually need to be changed**. In part, this may stem from the contribution of resilience thinking, which emphasises the value of transformability, while leaving open the question of precisely what or how to transform. Perhaps as a consequence, socio-ecological research into deliberate transformations embraces a rather diverse mixture of approaches and theoretical frameworks, including pathways approaches, socio-technical transitions thinking and social practice

Figure 1.4 Three perspectives on systemic challenges



Note: STS denotes 'science and technology studies'.

Source: Adapted from Loorbach, 2015.

theory, with differing focuses of analysis. As Steward notes in relation to the different actor groups working on transitions and transformations (and often employing concepts from resilience thinking), 'It is apparent from the different actor-oriented perspectives that the notion **of "system change" is grounded in quite different perceptions of the system or subsystem being addressed.'**

Local communities and places

Despite its slightly ambiguous framing, socio-ecological transformations research in practice focuses primarily on **nature-society interactions in specific places** (e.g. a forest, lake or watershed). Partly as a consequence, there is a tendency to focus more on issues such as land use or food production (in both developed and developing countries), rather than on technology-intensive systems such as mobility. It is also notable that this place-based focus on communities overlaps to quite an extent with the action-oriented perspective, as described by Steward.

Focusing on spatially defined systems has some important advantages. For example, it directs attention towards interactions and trade-offs across different systems and resource uses within a particular area, as exemplified by food-water-energy nexus assessments. In doing so, this type of analysis can illustrate the importance of issues such as spatial planning and land use. It can also highlight potential risks and synergies associated with changes in an individual system — for example the kinds of complex

social and environmental trade-offs associated with expanding cultivation of bioenergy crops (Giampietro and Mayumi, 2009). Acknowledging and understanding these interactions will be essential for societies to achieve sustainable outcomes.

At the same time, the place-based focus in socio-ecological transformations research also has some limitations. For example, in focusing on a confined area, the analysis pays limited attention to the broader production-consumption systems that drive environmental degradation and are often transboundary in nature. In doing so, it appears to ignore important actors and interests that can constrain or enable systemic change. As O'Brien and Sygna themselves acknowledge, the socio-ecological perspective 'glosses over power, politics and vested interests' and pays little attention to 'winners and losers in the transformation process' or 'links to the global political economy'. These are essential themes for understanding the drivers of unsustainability and barriers to transformation, yet they are likely to fall outside a place-based framing. As Steward also notes, ignoring value chains and networks can also make it hard for less place-based actors, such as businesses and trade unions, to engage with the new transitions discourse.

Functional and transboundary systems

Socio-technical transitions research offers a very different systemic focus. In focusing on **systems that meet societal needs**, the research is reasonably clear about what needs to transition. Moreover, this framing enables socio-technical research to pay due attention to the combination of interests, investments, institutions and other factors across (often transboundary) value chains that constrain or enable systemic change, potentially creating trade-offs or conflicts. This in turn enables socio-technical analysis to provide essential insights into barriers to change and how they can be overcome.

The socio-technical perspective arguably has limitations in terms of its tendency to focus on technology-intensive systems, such as energy and mobility, with weaker insights into areas such as food, water and land. Moreover, the emphasis on specific functional systems may weaken awareness of interlinkages and trade-offs across systems. Socio-technical transitions research focuses primarily on the role of technological change and innovation as enablers of systemic change with only limited analysis of the potential environmental impacts and feedbacks of large-scale adoption of new technologies and innovations.

In this respect, IAMs provide an interesting contrast. Although they share the socio-technical focus on achieving transitions in technology-intensive, large-scale and often transboundary systems of production and consumption, they pay particular attention to how demographic change or technological change can impact resource use, emissions reductions or trends in biodiversity, albeit often at a very aggregated level of analysis.

Globalised systems and deep structures

In their discussion of socio-economic systems, Kemp et al. address a mixture of systems and scales. This includes a focus on transboundary and often globalised **economic and financial** systems, which play a key role in shaping the production-consumption systems that meet human resource demands but are themselves subject to a variety of lock-ins.

Kemp et al. broaden the perspective further to address the socio-economic paradigm, which is understood to drive environmentally and socially undesirable phenomena such as competitive consumption, materialism, commodification and alienation. As a consequence, **transformation of the capitalist market paradigm is identified as a goal in itself**. This appears to contrast with the socio-technical perspective, which acknowledges the role of the macro-level landscape in shaping production and consumption but focuses attention on transition of the meso-level systems that meet societal needs. **According to socio-technical thinking, sustainability transitions may be broadly compatible with the prevailing liberal market paradigm**, although they may require some modulation of its assumptions.

Interestingly, Kemp et al. couple their macro-level focus on the economic paradigm with an emphasis on the role of micro-scale initiatives and personal change as a means to establish new types of economies. In this respect, there appear to be strong similarities with the socio-ecological perspective, which emphasises the importance of local activities as a means to achieve change in deeply engrained societal values and worldviews.

1.3.3 How do transitions and transformations occur?

Mainstream and systemic perspectives

As already discussed, Van Vuuren and Hof's paper on IAMs provides a fairly mainstream framing of the sustainability challenge facing societies in Europe

and elsewhere. It emphasises the scale and urgency of needed change and translates this into messages to inform priorities, targets and market-based instruments. These insights are grounded in an expectation that social actors (producers, consumers, policymakers) act as rational, cost-optimising agents.

In keeping with the foundational assumptions of neo-classical economics, this framing sees incentive structures (in particular market prices but also regulations and associated enforcement mechanisms) as determining whether or not society will achieve the needed systemic transformations. The perspective appears to be grounded in an understanding that market forces, in combination with state interventions to set targets and correct market failure, can guide society towards sustainability and related policy objectives.

The other four papers provide more systemic perspectives. In differing ways, they add complexity to the mainstream characterisation, highlighting major barriers to change and offering different insights into how those barriers can be overcome.

For example, the four papers question the economic assumptions that underpin mainstream understandings of systemic change, in particular **challenging the notion that, individually or collectively, humans respond to incentives in ways that lead to welfare-maximising outcomes**. In part this is due to the influence of cognitive biases, uncertainties and shocks. In part, it is a result of the fact that achieving a utility-maximising (Pareto efficient) outcome for society will almost certainly create losses for individuals, including well-resourced and politically influential incumbents. Systemic change necessarily disrupts and challenges established investments, jobs, behaviours, knowledge and values, generating resistance to change. Collectively, **these factors can significantly constrain policymakers in their ability to impose regulations and pricing instruments** that are consistent with long-term environmental goals.

Another shared theme is a perception that **increasing the efficiency of established systems of production and consumption has significant limitations and drawbacks** as a means of achieving sustainability. Some of this reasoning was already included in SOER 2015, which noted that efficiency improvements often reduce costs, incentivising increased consumption. (Indeed, as van Vuuren and Hof explain, IAMs themselves incorporate this kind of 'rebound effect' into their analysis.) The socio-economic, socio-technical and socio-ecological perspectives go beyond this reasoning, however, arguing that, although human efforts to maximise efficiency have contributed to the surge in economic output since the industrial revolution, they have also increased vulnerability, hampered system innovation and produced harmful externalities. For example:

- The socio-economic literature notes that markets have enabled major productivity increases by incentivising specialisation, division of labour and minimisation of redundancy. However, the resulting shift towards increasingly globalised value chains and economic networks has brought with it widely dispersed externalities, systemic risks and other forms of market failure.

- Socio-technical research extends this critique, noting that the division of labour into specialised silos within individual businesses and industries also contributes to lock-ins because each unit has incentives to focus on optimising individual aspects of a technology rather than questioning the technology as a whole (Unruh, 2000). Calls for transdisciplinarity and the co-creation of knowledge to support sustainability transitions likewise reflect an acknowledgement of the limitations of academic and organisational silos.

- Socio-ecological and resilience research offers the insight that attempts to optimise aspects of a system tend to reduce the space for redundancy in the system, thereby increasing vulnerability to shocks and potentially increasing systemic risks as adaptive capacity is reduced.

These insights do not imply that all efficiency improvements are problematic. On the contrary, achieving the EU's 2050 vision of 'living well, within environmental limits' will necessitate huge efficiency improvements. However, they do highlight some limitations to efficiency maximisation strategies, and point to the concurrent need for more fundamental changes in ways of living.

Transforming complex societal systems: 'revolutionary' and 'reconfiguration' approaches

Collectively, the socio-ecological, socio-technical, socio-economic and action-oriented perspectives appear to share an understanding that lock-ins, feedbacks and uncertainties significantly constrain markets and policymakers in enabling systemic change.

Turning to the question of how societies can overcome these barriers and achieve transitions, the different perspectives vary in emphasis, for example in terms of the prominence given to technologies versus social innovations; production versus consumption; and

local action versus broader systemic change. These differences are a matter of degree, however, rather than being absolute.

Where the perspectives appear to differ more fundamentally is in their frameworks for understanding how activities at the micro scale link to broader systemic change. As already indicated in the previous section, 'What needs to be transformed?', the socio-ecological and socio-economic perspectives emphasise the potential for **grassroots innovation and local initiatives** to catalyse **macro-scale change in the economic paradigm and cultural values**, which are regarded as the core underlying drivers of unsustainability. In contrast, the socio-technical perspective focuses on the **interplay of landscape and niche-level activities** in enabling change in **meso-level functional systems**. Geels et al. (2015a) propose that these two analytical positions on systemic change represent 'revolutionary' and 'reconfiguration' approaches (in contrast to the mainstream 'reformist' approach grounded in neo-classical economic orthodoxy).

Of these two positions, the socio-technical 'reconfiguration' approach appears to provide a clearer and more comprehensive framework for understanding the dynamics of transitions. In particular, the MLP presents a logic that explains how the interplay of innovation and disruption at different scales brings about systemic change (Figure 1.5). Like the IAM approach, socio-technical analysis acknowledges the role of market forces in driving upscaling and diffusion, yet it also emphasises the co-evolution of technologies, institutions, norms, practices and so on. Alongside this analytical framework, socio-technical research boasts a strong historical evidence base on how large-scale socio-technical transitions have occurred in the past (albeit not transitions to agreed sustainability objectives).

In some important respects, **the alternative 'revolutionary' approach appears to lack a comparable analytical framework and evidence base**. Admittedly, there is ample evidence that local communities can devise solutions to collective action problems and create new ways of living. There are also frameworks that indicate how local practices and initiatives can feed into broader systemic change. These include Ostrom's writings on polycentric governance (Ostrom, 2010a), Meadows' work on leverage points (Meadows, 1999), and the growing body of thinking on how local social innovations can effect large scale system change through different modes of scaling (Moore et al., 2015). In practice, however, there is often a significant mismatch between such grassroots activities and the global scale of sustainability challenges. It is frequently hard to quantify the impacts of local initiatives, particularly in terms of rather nebulous effects such as changing beliefs and attitudes. Moreover, activities that produce desirable outcomes at local scales (such as using biomass to produce energy) may generate significant environmental and social trade-offs when upscaled across society.

As Steward notes, 'A key challenge recognised by many of these action-oriented perspectives is how to combine their situatedness with wider change.' Similarly, while emphasising the potential leverage of interventions that alter attitudes and values, O'Brien and Sygna acknowledge that the socio-ecological perspective 'lacks a coherent framework for bringing together the subjective attributes of individuals and groups with objectively measurable changes in behaviours and systems.'

Shared understandings of systemic change?

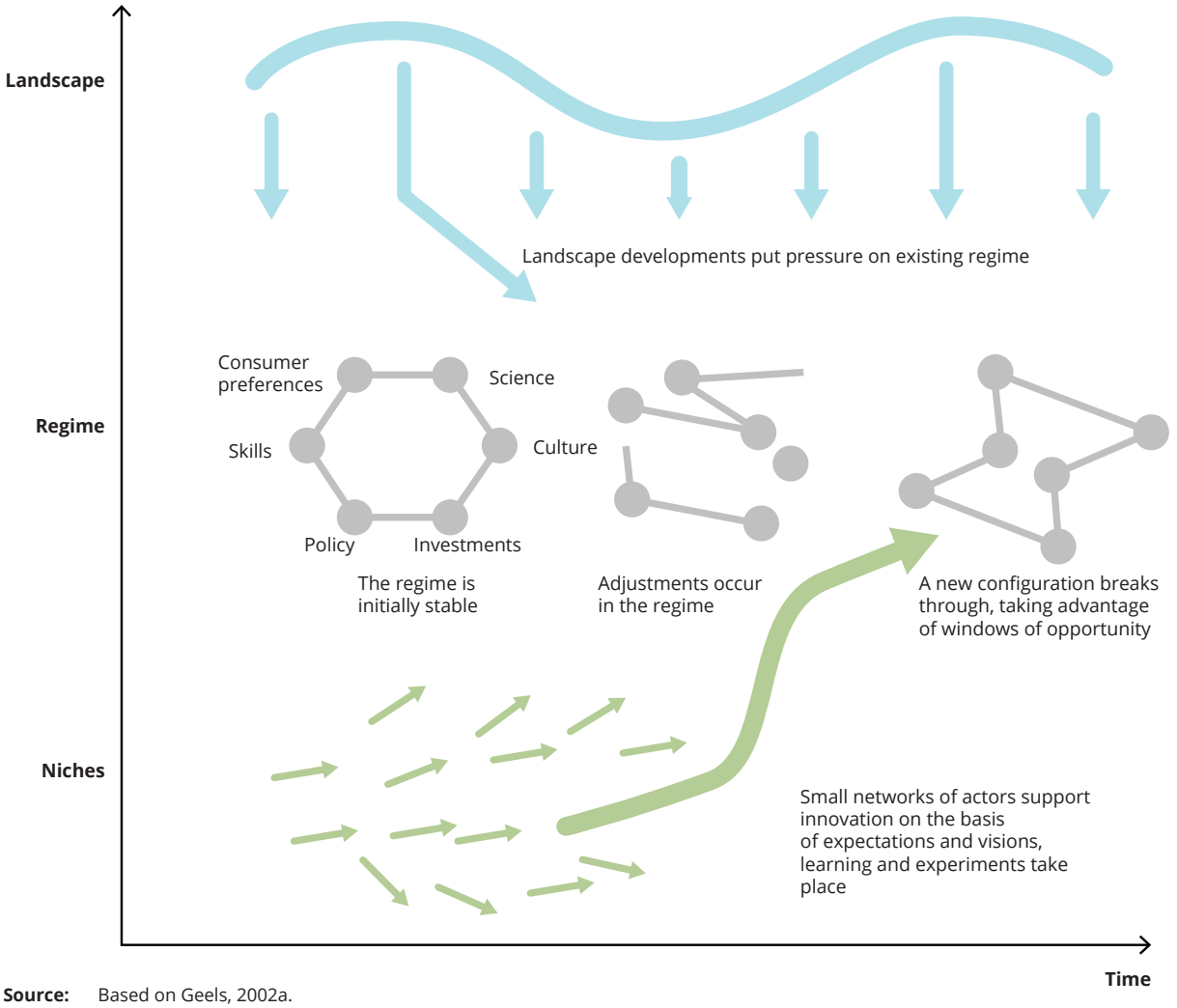
While the differentiation of 'revolutionary' and 'reconfiguration' approaches is useful, the two approaches are not wholly distinct. First, writers on change in the socio-economic paradigm such as Polanyi (1944), Tilly (1992) and Freeman and Louçã (2001) have emphasised the co-evolution of technologies, practices, values and beliefs, in ways that resonate strongly with the socio-technical perspective. Second, more recent research by academics such as Adrian Smith (2012) and Maja Göpel (2016) employs the MLP as a framework for explaining the role and influence of grassroots innovation, interpersonal relations and macro-level paradigms.

As such, there appears to be some **important and perhaps growing common ground between the different systemic perspectives**. For example, across the socio-ecological, socio-technical and socio-economic perspectives:

- Policymakers and institutions are generally perceived to be part of the system that needs to be transformed, rather than being separate actors with the power to steer society towards long-term sustainability objectives.

- Systemic change is understood to depend on more **multi-scalar, society-wide** processes of innovation, experimentation and learning; **upscaling, replication or adaptation** of new technologies or practices; and **disruption** of the established regime, often as a result of external shocks.

Figure 1.5 Multi-level perspective on socio-technical transitions



Source: Based on Geels, 2002a.

- Transitions are **multi-actor** processes that involve interdependent changes in technologies, behaviours, rules, values and so on. The complexity of the related interactions and feedbacks implies that transitions produce highly uncertain, emergent outcomes.

Again, it is noteworthy that the emphasis on radical innovation, external shocks and non-linearity contrasts quite strongly with mainstream modelling perspectives, which struggle to integrate these factors. Yet it is also apparent that the systemic perspectives **also embrace, to some extent, mainstream understandings of how systemic change occurs**. For example, the socio-ecological and socio-economic perspectives include mainstream 'reformist' governance tools, such as financial regulation, fiscal reform and intergovernmental agreements, alongside their more 'revolutionary' focus on changing paradigms and worldviews.

1.4 Steering transitions: implications for policy, governance and knowledge

From the preceding discussion, it is apparent that the five papers presented in this report adopt rather different positions on the role of governments in achieving sustainability transitions. The integrated assessment modelling perspective is grounded in the idea that governments are able to set targets and create rules and incentives in ways that enable market forces to steer us towards long-term sustainability goals.

To varying degrees, the other four perspectives are more cautious about the potential role of government. Central to this scepticism is **a perception that state institutions and policies contribute to perpetuating the established regime**, since any changes in existing rules and structures are likely to generate trade-offs across society that generate resistance. Furthermore, in emphasising the hugely complex, uncertain and emergent character of societal transformations, the systemic perspectives also question whether governments can ever have the knowledge and tools to pilot society towards sustainability.

These are important insights, which point to the critical importance of innovation and broader societal engagement in systemic change, as well as the need to embrace a more diverse mixture of governance approaches, including adaptive, polycentric and participatory styles. Taken to an extreme, however, scepticism about the role of government can devolve into a perception that the state is part of the problem, rather than part of the solution. Steward notes, for example, that 'An unfortunate counterpart to the innovativeness regarding transition governance practices is a weak connection with formal governance structures. At its worst this is presented in an antagonistic fashion (board room versus city hall, community versus local authority) rather than as new opportunities for interaction.'

This characterisation of government seems to be misleading and unhelpful for several reasons. First, it represents a simplistic characterisation of government as a monolithic entity, rather than comprising heterogeneous actors with diverse goals and constraints. Second, it is empirically highly questionable. Governments have played a central role in triggering some of the most obvious instances of systemic change during recent times, for example in the form of Germany's Energiewende or the uptake of electric vehicles in Norway. Conversely, attempts to catalyse sustainability transition simply by fostering experimentation and learning have been disappointing (Hoogma et al., 2005).

A more nuanced understanding acknowledges the constraints on government actions but also recognises that governments have an essential role to play, albeit not as a pilot with the full knowledge and powers to plan and implement transitions. Governments have unique capacities, resources and authority to identify and agree society-wide goals and targets, to create institutions and networks, and to facilitate structural socio-economic change. Rather than perceiving the state as part of the problem, it seems more appropriate to consider how governments can best use their powers to enable transitions — not only by means of hierarchical legislating but also by creating the institutions and infrastructures to enable markets and networks to function. As Rodrik (2011a) notes, 'Markets and governments are complements, not substitutes. ... Markets work best not where states are weakest, but where they are strong.' By the same reasoning, governments have an essential role to play in helping catalyse and coordinate polycentric and network governance forms, based on social interaction and information sharing.

Mainstream policy approaches: limits and opportunities

As described by van Vuuren and Hof, integrated assessment modelling differs from the other perspectives in offering a mass of forward-looking, quantitative information about pathways to possible futures, with clear messages for policymakers. In particular, IAMs provide insights into the costs of alternative pathways, which can help in establishing targets and objectives, and in designing policies to achieve those targets. With their grounding in mainstream economic reasoning, IAMs strongly prioritise the role of economic instruments (e.g. environmental taxes or emissions trading) in enabling society to achieve its goals in an efficient and cost-effective way.

In a mixture of ways, the other four perspectives question this mainstream policy framing. Key among these criticisms is the perception that resistance from incumbents and consumers, as well as the difficulties of responding to collective action problems in a globalised marketplace, effectively make it impossible for governments to impose sufficiently stringent regulations and pricing instruments. At the same time, the systemic perspectives do not reject mainstream environmental policy approaches outright but rather present a more nuanced account of their contingent role in shaping and or hindering transitions, as well as offering insights into how such approaches can be enabled and complemented.

For example, one theme highlighted in the socio-ecological, socio-technical and socio-economic papers is the notion that **disruptions can create windows of opportunity** that enable policymakers to tighten policy targets. These could include external, landscape-level events such as the Fukushima nuclear disaster or the financial crisis. But the socio-technical and socio-economic perspectives extend this reasoning further, highlighting the way that innovation at the local level can also produce windows of opportunity to advance policy. For example,

new technologies can make it cheaper to achieve environmental goals, alleviating resistance to more demanding policy targets and international agreements (Geels et al., 2017). Similarly, Kemp et al. argue in their paper that social innovations that create alternative ways of satisfying human needs can weaken political lock-in to the growth paradigm.

The systemic perspectives also point to the need to complement environmental policies with a much more diverse mixture of policy approaches. Regulations and environmental taxes still have an important role to play, for example in disrupting the established regime. But achieving systemic change is likely to depend to a significant extent on creating an environment in which novel technologies, practices and business models can emerge through experimentation and subsequently displace established ways of meeting societal needs. This may necessitate adopting **different governance styles at different stages of transitions**.

For example, innovation can be supported by means of innovation policy (e.g. public funding for research and development) but can also benefit from novel governance approaches, such as strategic niche management or transitions management, which emphasise experimentation and networking. Once particular technologies or practices have demonstrated their viability, there may be a greater role for more traditional policy approaches, such as industrial policy (e.g. in the form of adoption subsidies or public investments), as well as education and welfare policy (e.g. retraining and income support to alleviate resistance to structural economic change).

As a counterpart to the emphasis on transformation of unsustainable systems, the socio-ecological perspective also draws attention to the value of **preserving and enhancing resilience** where it can help prevent harmful regime change. This points to the importance of different types of measures, including improving green infrastructure and nature-based solutions. Resilience thinking also points to the need to build redundancy into systems to help them absorb shocks and adapt to new state.

Cities and networks

Communities and cities emerge as key actors across the different perspectives, reflecting the capacity for innovation to emerge in local settings, the potential for local systems (e.g. energy, mobility) to transform quite dramatically over relatively short timescales, and the often considerable budgets and decision-making powers available to local administrations. Cities often constitute socio-political niches within a national context — frequently characterised by comparatively progressive politics and potentially less susceptible to pressure from incumbent industries. For example, it may be easier for city administrations to ban the use of polluting cars within their jurisdictions than for a national government to do the same, although the impacts of local actions of this sort may influence producer and consumer choices at broader scales.

The impact and influence of local initiatives is enhanced by new **platforms for networking and communication**. Such platforms can facilitate the sharing of ideas and practices across 'communities of communities', which allow innovations to be shared, replicated and adapted. Networks of this sort can emerge spontaneously but often benefit from centralised support and infrastructure that enable local administrations, civil society actors, businesses and so on to interact. Examples include 'platforms of action', 'stakeholder platforms' or 'transition arenas' created pursuant to policies and initiatives such as the 2015 Paris Agreement, the 2012 Global Covenant of Mayors and the EU's 2015 Circular Economy Strategy.

Coordinating and steering transitions

Despite their differences in emphasis, the socio-ecological, socio-technical and socio-economic perspectives share an understanding that transitions rely on innovation and reconfiguration across multiple areas of society. They are multi-scalar processes, dependent on policy mixes and governance interactions across the local, national and international scales. A major governance challenge therefore resides in steering such uncertain and wide-ranging processes of change towards desirable end points. Here, government interventions can contribute in a variety of important ways.

The first is in creating **shared goals and frameworks** to steer and coordinate activities. Part of this is achieved through international agreements and strategic policy frameworks at broad geographical scales. As O'Brien and Sygna note, 'international institutions and agreements are considered important, both to provide a framework for action and to support the incentives, monitoring and reporting mechanisms necessary for successful transformations'.

The UN Sustainable Development Goals provide an obvious example of internationally agreed targets that can help orient activities across scales. Similarly, strategic policy frameworks have emerged in Europe during recent years that set out long-term targets, for example in relation to transformation to a circular and low-carbon economy. Again, these have the potential

to inform and shape visions, policy and governance at national, regional and local scales.

The importance of **scenarios and roadmapping** is highlighted across the five perspectives on transitions. Foresight approaches can help in engaging communities in participatory processes that develop narratives or 'imaginaries', which can help illustrate the implications of alternative futures. Integrated assessment modelling provides a powerful tool for exploring different pathways to society's goals. Collectively, forward-looking approaches can provide valuable insights into the urgency of action, where to target efforts and investments, and the kinds of trade-offs that may arise during transition processes.

In addition, achieving sophisticated policy mixes and coordinated governance is also likely to require changes in **public sector institutions, competencies, skills, and knowledge systems**. Tackling complexity and achieving transitions will depend in part on overcoming silos and enabling information to flow freely across government and across scales. It will also require the development of adaptive governance frameworks that operate via iterative cycles of planning, implementing, monitoring and learning.

New knowledge for transitions

Knowledge creation, sharing and use are fundamental to the governance of sustainability transitions (indeed, this report represents a response to that need). It is apparent, for example, that the role of the state and of public policy is currently underdeveloped in transitions research (Johnstone and Newell, 2017), pointing to the need for investments in knowledge development in this area.

Yet developing the knowledge needed to support transitions presents diverse challenges and will require, in some senses, a transformation of the existing knowledge system. Some of the needed changes have already been mentioned in the preceding paragraphs, including the creation of open governance structures that promote knowledge sharing across government and society more broadly, and the development of more forward-looking information. The latter cluster of knowledge includes foresight activities such as horizon-scanning, which can help identify emerging risks associated with complex and uncertain transformation processes.

In shifting knowledge development away from a focus on environmental problems towards a greater emphasis on how society can respond, another key priority for knowledge development relates to **practice-based evidence**. Several of the papers highlight the importance of case studies and practice-based evidence in illustrating complex, multi-dimensional processes such as transitions. Steward further highlights the power and communication potential of the exemplary case study, as well as the potential for 'platforms of action' to collect practice-based evidence, helping to upscale successful actions (and avoid duplicating unsuccessful initiatives).

At the same time, the use of case studies creates some challenges. Substantial resources and skills are required to collect case studies in a methodologically rigorous way and assess whether and how they can contribute to systemic change. As Steward notes, the qualitative and heterogeneous character of such knowledge can make it difficult to capture, categorise and share. This is particularly the case because the communities lack a shared set of transition concepts, or even a shared perception of what system or subsystems are being addressed. These realities point to the need to develop appropriate categories, methods and frameworks.

More broadly, the transitions perspectives are broadly united in calling for more transdisciplinary and co-creative knowledge. At present, knowledge development often operates in silos, which are reinforced by factors such as academic incentives, established routines and skills, and contrasting epistemological and ontological foundations. As is increasingly acknowledged, this is deeply problematic as no single disciplinary perspective can explain global sustainability challenges, their causes or how society should respond (IGBP et al., 2001).

In summary

Transitions in the societal systems that drive environmental degradation and climate change are essential if Europe is to meet its sustainability goals in coming decades. Despite their contrasting theoretical foundations and analytical approaches, the research domains addressed in this report offer many shared insights into how transitions could be achieved, including in terms of the governance practices and knowledge approaches needed to effect such fundamental changes.

These shared insights still remain largely in the research domain with limited uptake in established governance structures and institutions. The challenge in coming years will be to bring these insights into mainstream policy processes and consider how they can be operationalised effectively in support of Europe's sustainability objectives.

2 Transformations in socio-ecological systems

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2.1 Introduction

This chapter examines deliberate transformations in socio-ecological systems in response to sustainability challenges. Global environmental changes, including climate change, biodiversity loss, changes in biogeochemical cycles, and land use and land cover changes, introduce new and in some cases unprecedented risks to natural and social systems, with implications for ecosystem services, food, health and human security. In addition to the growing risks to particular groups, species and ecosystems, the risk of exceeding thresholds or 'planetary boundaries' draws attention to the global nature of the challenge and the need for large-scale, rapid and systemic transformations to sustainability (Steffen et al., 2015b).

A socio-ecological system, sometimes referred to as a 'social-ecological system', can be described as a coherent system characterised by interconnections, mutual dependencies and dynamic relationships between humans and the environment. The concept has become increasingly used with the growing recognition of the importance of integrating biogeophysical, social and human dimensions in analyses of sustainability at all scales. Nevertheless, the concept of socio-ecological systems can be interpreted and operationalised in different ways. Interpretations of socio-ecological systems range from simply combining humans and nature into one 'coupled' system to those that consider humans as being 'in nature' or as 'part of nature'. Many see the delineation and distinction between the social and ecological as artificial and arbitrary (Folke et al., 2005), with some conceptualisations of socio-ecological systems recognising that humans 'are' nature (Alaimo, 2010; Weber, 2013).

The differing perceptions and interpretations of socio-ecological systems are significant for understanding whether and how transformations to sustainability can be catalysed, managed or governed, with implications for both policy and practice. Attention to socio-ecological transformations is timely and relevant, particularly in light of the 1.5 °C target established by the 2015 Paris Agreement under the United Nations Framework Convention on Climate Change.

Definitions of transformation

Transformation within the context of socio-ecological systems generally refers to significant or fundamental changes in a system. The Intergovernmental Panel on Climate Change (IPCC) defines transformation as 'a change in the fundamental attributes of natural and human systems' (IPCC, 2014b). This includes pursuing pathways or trajectories to meet goals for limiting greenhouse gas emissions, reducing atmospheric concentrations of greenhouse gases and/or minimising global mean surface temperature changes (IPCC, 2014b). Importantly, meeting these goals calls for changes that go beyond influencing energy systems and carbon dioxide emissions. They instead imply wider and deeper transformations that reduce risk and vulnerability while protecting the viability and integrity of the atmosphere, biosphere, hydrosphere and cryosphere to support the well-being of species, including humans, both now and in the future (O'Brien and Selboe, 2015a).

Within the social realm, transformation can be thought of as 'a process of altering the fundamental attributes of a system, including structures and institutions, infrastructures, regulatory systems and financial regimes, as well as attitudes and practices, lifestyles, policies and power relations' (Hackman and St Clair, 2012). Although transformations can be either negative or positive, discourses on deliberate transformations usually have implicitly positive connotations. For example, Kofinas and Chapin (2009) emphasise that 'transformation is the conversion to a new, potentially more beneficial, state with new feedbacks and controls when existing ecological, economic, or social structures become untenable.' Park et al. (2012) define transformation as 'a discrete process that fundamentally (but not

necessarily irreversibly) results in change in the biophysical, social, or economic components of a system from one form, function or location (state) to another, thereby enhancing the capacity for desired values to be achieved given perceived or real changes in the present or future environment'. Aside from these rather complex definitions, the concept of transformation is also used loosely and metaphorically, sometimes referring to any process of change (Feola, 2015).

Over the past decade or so, 'transformation' has been increasingly used to describe a range of desirable responses that are considered necessary to meet the broader challenges of global sustainability, including the targets established under the United Nations Sustainable Development Goals (SDGs).

Although 'green transformations' to sustainability are considered both necessary and desirable by many, the concept of transformation itself can be contentious and controversial. As emphasised by Scoones et al. (2015), 'rather than being one big green transformation, it is more likely that there will be multiple transformations that will intersect, overlap and conflict in unpredictable ways. ... We are likely to see a series of competing — at times divergent, other times convergent — green transformations.'

The notion of transformation itself is viewed by some countries or groups as politically undesirable because it does not specify who does the transforming and towards what goals. For example, in the case of the IPCC Fifth Assessment Report (2014b) the definition of transformation was amended in the plenary approval session for the Working Group II Summary for Policymakers to recognise the importance of goals and values: 'A change in the fundamental attributes of natural and human systems. Within this summary, transformation could reflect strengthened, altered, or aligned paradigms, goals, or values towards promoting adaptation for sustainable development, including poverty reduction.' As a result of its political nature, the concept of transformation is likely to be avoided in subsequent IPCC reports.

Transformations can be defined more generally as significant changes in form, structure and meaning-making (O'Brien and Sygna, 2013). This definition recognises transformation as an emergent property of systems, as well as a political and human process, and it acknowledges both quantitative and qualitative dimensions to transformation. Recognising that transformation can mean many different things opens up a variety of possible approaches and outcomes.

2.2 Conceptual background and assumptions

The concept of 'transformation' describes changes taking place within a wide variety of contexts and operating within and across multiple scales. Transformations of socio-ecological systems are closely linked to the concepts of adaptation, mitigation and resilience, which themselves are not discrete.

Adaptation is broadly defined as changes to suit different conditions. In relation to climate change it is considered to be 'the process of adjustment to the actual or expected climate and its effects' (IPCC, 2014b). Transformational adaptation is increasingly recognised as a necessary response to climate impacts and other stressors (Kates et al., 2012; Park et al., 2012). This can refer to actions that are adopted at a larger scale, that are new to a region or resource system, or that transform places or shift locations (Kates et al., 2012). In terms of reducing the risks of climate change, mitigation of greenhouse gases can be considered an important adaptation strategy.

Climate change mitigation refers to efforts to reduce emissions of greenhouse gases to the atmosphere. It is clear that adaptation and mitigation are closely related: the more that global temperatures increase, the greater the need for adaptation. In the context of mitigation, transformations are often considered synonymous with climate stabilisation pathways (Clarke et al., 2014). In contrast to a focus on transformations of socio-ecological systems, the discourse on mitigation tends to favour the language of transitions or pathways. The strategies most often associated with climate stabilisation pathways include investing in and using renewable energy, developing more energy-efficient technologies, changing management practices (e.g. for agriculture and forests) and altering individual behaviour and lifestyles (IPCC, 2014b). Such strategies are largely technical, carried out within existing systems rather than significantly transforming them.

The concept of resilience emphasises transformability, which refers to the ability of an adaptive system to respond to changes in uncertain, surprising and unpredictable ways. Transformability draws attention to incremental and abrupt changes and the relationship and interplay of both slow and fast variables across scales (Folke, 2006). In ecological systems, slow variables are those that have a controlling or stabilising effect, while fast variables are more sensitive to systemic perturbations (Walker et al., 2012). In other words, a resilient system can be transformed to adapt to new situations. However, resilience can also be

interpreted as a characteristic of systems that resist transformation (Pelling, 2011).

Global change research often considers concepts such as adaptation, mitigation and resilience within the context of multiple stressors that can generate barriers and opportunities for transformation. For example, economic changes and crises can limit investments in innovative technologies, or they can catalyse social innovations and the potential for transformative change. Within the context of biodiversity conservation and management, it has been shown that interventions such as payment schemes, alternative livelihood programmes and buffer-zone projects often fail to take into account the existing dynamics and complexity and thus fail to create the desired results (Milner-Gulland, 2012).

The interaction of multiple processes of change adds to the complexity of socio-ecological systems and can make causal relationships even more ambiguous and outcomes more unpredictable. Research recognises that human efforts to manage the environment and ecosystems can produce counter-intuitive outcomes in complex systems. Consequently, transformations in socio-ecological systems place a strong emphasis on learning, experimentation and adaptive management. There is also growing attention given to values, interests and power relationships as a means of making transparent who decides on the types of transformations that are feasible, desirable and affordable, and which trade-offs and losses are considered acceptable (Pelling and Manuel-Navarrete, 2011).

2.2.1 Assumptions of urgency, global responsibility and management

Transformation of socio-ecological systems at the rate, speed, magnitude and depth that is called for by global environmental change science involves transparency about core assumptions that may be accepted by some, disputed by others, and overlooked by many.

The premise for deliberate transformations of socio-ecological systems is related to the critical nature and urgency of addressing global environmental problems. The concept of the Anthropocene, a proposed geological epoch in which humans are recognised as a major geological force on the planet, is increasingly used to frame research on transformations in socio-ecological systems (Steffen et al., 2011). The notion of 'planetary boundaries' has also played an important role in framing research on human-environment interactions, recognising that systemic interactions and non-linear dynamics may push systems beyond thresholds that support humans and the ecosystems that they depend upon (Steffen et al., 2015a). Scientific research suggests that unprecedented socio-ecological challenges are imminent unless deliberate transformations to sustainability are successfully pursued. The urgency of human responses is based on the recognition that there is still a limited window of opportunity for humans to collectively recognise and respond to the challenge of global environmental problems (Anderson, 2015). Normative research on socio-ecological transformations implicitly or explicitly assumes that sustainability, resilience and equity are desirable and shared characteristics of global society.

These unifying global framings have also been criticised by some social scientists, however, for not taking into account regional differences in social contributions to environmental problems, varying capacities to respond, and the uneven outcomes that are produced by global change processes, i.e. the fact that there may be both perceived and real winners and losers (Lövbrand et al., 2015). Many groups have long been affected by extractive and polluting industries, land expropriation, resource grabbing, waste dumping and other forms of environmental injustice. Global framings seldom capture the root causes of the problem, which include the organisation of the global capitalist system and the distribution of power that supports vested interests (e.g. the petroleum sector) that benefit from current systems (Pelling et al., 2011; Wilhite, 2016). They instead promote an apolitical approach to environmental issues in which policies are increasingly sustained by populist gestures that seldom contribute to real change (Swyngedouw, 2010).

Much of the literature on socio-ecological transformations implicitly assumes that they can and need to be initiated, directed, managed and governed, which creates tensions with the idea of transformations as open-ended, emergent and highly unpredictable (Patterson et al., 2016). 'Command and control' approaches fail to recognise transformation as an organic, multidimensional process that defies top-down and bottom-up dichotomies. A managerial approach also contributes to controversies and resistance, particularly by those who are 'being transformed' (Stirling, 2015).

Intentional social change can indeed be viewed suspiciously, including by those who do not accept the urgency of responding to global environmental change. Yet transformations to sustainability can still be nurtured, supported and accelerated by paying attention to and committing resources towards key institutions and actors at critical points in time. The notions of leverage points, 'aikido moves' and 'trim tabs' have been used to emphasise that systems

are not linear and deterministic, and can be skilfully influenced in non-intuitive ways (Meadows, 1999; Fuller and Snyder, 2008). Governance can also serve as a means of creating the conditions for transformation (Patterson et al., 2016).

2.2.2 Linking across systems and scales

A systems approach is the hallmark of research on socio-ecological transformations. Transformation as a fundamental and non-linear change in the nature of a system can appear as radical shifts, directional turns or step changes that can be 'either forced by systems failure or chosen in anticipation of collapse and movement to a novel socio-ecological systems state' (Pelling et al., 2015). A systems approach also pays attention to discontinuities and thresholds that increase the potential for regime shifts (Folke et al., 2009).

Understanding the dynamic interactions within and across socio-ecological systems and scales is considered critical to understanding transformation processes. Globalisation processes in particular are creating both tensions and opportunities for transformation, resulting in increased attention to the role of global economic and financial systems and how they together influence processes, responses, and outcomes in socio-ecological systems. For example, research points to how cultural changes may lead to increased meat consumption or 'suburbanisation' of housing structures (Leichenko and O'Brien, 2008; Leichenko and Solecki, 2013). Changing trends and patterns in consumer preferences, such as the demand for bluefin tuna, can have widespread impacts on marine ecosystems and fisheries through lawful and unlawful resource exploitation (Berkes et al., 2006). Alternatively, awareness of the relationship between investment capital and non-renewable energy use can spread incrementally and evolve into a global divestment campaign to draw attention to the relationship between finance and fossil fuels.

Research related to the transformation of socio-ecological systems covers a range of time horizons, but the relationship between short-term actions and longer term implications is usually emphasised. The long term most often relates to the end of the current century, but it is also recognised that socio-ecological transformations will have much longer lasting consequences for society (Levermann et al., 2013). Research on both adaptation and transformation often draws on historical cases for insights that may be relevant to current and future scenarios (Orlove, 2005). An analysis of past collapses reveals that collaboration and learning can be a key to resilience (Butzer and Endfield, 2012).

Although the call for transformations is increasingly global, the scope of research on the transformation of socio-ecological systems is often regional and local, merging the macro and micro across temporal scales. Regional and local case studies provide important examples and insights into the transformative potential of different systems and sub-systems. At the same time, an emphasis on cross-scale interactions provides a basis for understanding how to bring them to scale in support of global transformations to sustainability. Transformation is assumed to be a non-linear and non-teleological process that is often considered to follow stages or phases, as will be discussed below (Feola, 2015).

2.2.3 Transformation extends beyond disciplinary boundaries

The conceptual framing of transformations in socio-ecological systems is closely linked to integrated research that includes perspectives and methods from the natural sciences, social sciences and humanities. Communities involved in the broader field of global environmental change research range from researchers working on Earth systems science and sustainability science to those focusing on the resilience of socio-ecological systems and stewardship of the biosphere. However, a distinction can be made between those studying observed and projected transformations of global systems in response to human activities and those studying deliberate transformations to sustainability through social change. Although these two approaches are intricately linked, natural scientists play a prominent role in the former and social scientists in the latter.

The social sciences have contributed important perspectives by linking socio-ecological transformations to multiple processes of change and diverse social contexts; by identifying how social and biophysical processes interact with the political economy; and by analysing how uneven distributions of power may prioritise or rationalise some outcomes over others (Hackman and St Clair, 2012). Social science framings make a distinction between business-as-usual approaches and those that challenge economic, social and political processes and relations that maintain the status quo. Transformations that do not take into account the roles of power, politics and interests are likely to prioritise dominant techno-managerial approaches, as opposed to more transformative

alternatives (Manuel-Navarrete, 2010; Norgaard, 2011; Wilhite, 2016).

Nonetheless, there is growing recognition of the benefits of transdisciplinary approaches to research, which are both problem and solution oriented and involve stakeholders and society in both defining and addressing environmental challenges (Wickson et al., 2006). Transdisciplinarity emphasises interaction and collaboration between researchers, policymakers, business leaders, entrepreneurs, non-governmental organisations (NGOs), practitioners, artists, citizens and social movements engaged directly or indirectly with transformations to sustainability. Transdisciplinary research builds on knowledge from disciplines such as geography, geology, ecology, economics, biology, atmospheric sciences, political science, oceanography and many others. For example, there is a long tradition of research on transformations in human-environment relationships in disciplines such as geography (Turner et al., 1990). Although such disciplinary knowledge is still considered important, necessary and useful, the inherent complexity of problems and solutions related to socio-ecological systems calls for bringing together diverse types of knowledge and methodologies. Yet as Folke et al. (2009) note, 'the integration of the human and environmental dimensions for ecosystem stewardship is still in its infancy...'.

2.3 Understanding and conceptualising transformations to sustainability

Research on transformations to sustainability in socio-ecological systems is a relatively new field within global change research. It is one of three research themes included in Future Earth, a 10-year global change research initiative, which draws attention to transformation in two of its key focal challenges (e.g. decarbonising socio-economic systems and increasing resilience to future threats). As discussed above, the transformation concept integrates a wide range of research from communities working on resilience, socio-technical transitions, social practices, social studies of science and technology, Earth system governance, behavioural psychology, communication and other fields (Westley et al., 2011; Brown, 2013; Feola, 2015). Transformations in socio-ecological systems can be studied through a number of approaches, as discussed by Feola (2015) and Patterson et al. (2016). Focusing on socio-ecological systems, the discussion below addresses resilience approaches and pathways approaches, then presents a more generalised understanding that focuses on three 'spheres' of transformation. However, it is first useful to consider some characteristics common to approaches to understanding socio-ecological transformations.

2.3.1 The process and dynamics of transformations

Research on transformations in socio-ecological systems tends to be normative and prescriptive, based on the assumption that sustainability is both urgent and necessary (Patterson et al., 2016). In contrast to traditional Earth systems research, which is largely descriptive and analytical, much research on transformations of socio-ecological systems is solutions oriented, seeking to engage with society through post-normal science or action research that is co-designed and co-produced with society (Future Earth, 2013; Feola, 2015). Such approaches recognise that knowledge cannot simply be produced, communicated and delivered to decision-makers, with the expectation that policies will then be made and implemented.

Research on transformations of socio-ecological systems often makes a distinction between incremental and transformational change, with incremental changes representing small adjustments made in response to perceived or expected changes, and transformational change corresponding to alterations that have systemic consequences (Park et al., 2012). This is particularly visible in adaptation research, which looks at processes of deliberate change in anticipation of, or in response to, stressors and stimuli (Nelson et al., 2007). However, the distinction between incremental change and transformative change blurs easily, especially if transformation is viewed as a non-linear process whereby changes that appear to be incremental lead, over time, to large-scale, transformative changes (Patterson et al., 2016). For example, small and incremental additions of nitrogen fertiliser can contribute to a regime shift in freshwater lakes from aerobic to anaerobic conditions. Similarly, incremental purchases of organic produce by consumers can contribute to transformative changes in farming and marketing practices.

Research on socio-ecological systems shows that transformations can be gradual or abrupt, and often they are episodic, occurring every once in a while as in the case of forest fires or institutional reorganisation (Holling and Gunderson, 2002). Transformations can also be conceptualised as evolutionary processes, recognising that social and cultural norms, rules and institutions evolve over time yet may also change in non-linear ways (Gladwell, 2000; Ostrom, 2014). The potential for abrupt change in socio-ecological systems draws attention to the existence of multiple equilibria and the role of uncertainty, surprises and

socio-ecological tipping points, i.e. instances when small perturbations can result in transformative change. Research suggests that there are some tell-tale signs or signals of tipping points. (Scheffer, 2010), for example, found that systems close to a tipping point become very slow to recover from perturbations. Other indicators of impending transitions in socio-ecological systems include increasing variance and skewness of fluctuations (Scheffer, 2010).

Uncertainty plays an important role in both descriptive and prescriptive approaches to transformations. There are different kinds of uncertainty, not only linked to understandings of biophysical processes, but also to developments in society, technology and cultural norms, including changing values and worldviews. For example, deliberate transformations that involve human agency and social processes introduce uncertainty into future scenarios because free will, intentionality, collective action and changing power distributions can be difficult to model, as they depend on relationships between agency and structures and between individuals and groups. Yet social tipping points have received increased attention in recent years, recognising that humans respond reflexively to collective risks in surprising ways (Bentley et al., 2014). For example, Nyborg et al. (2016) discuss how changing social norms can trigger large-scale transformations, such as the cessation of smoking in public places and changes in fertility norms.

Recognising that multiple transformations will be necessary to achieve broad, deep and rapid changes, and that these may be open-ended and involve unpredictability and uncertainty, it can be useful to consider diverse conceptualisations and frameworks for understanding transformations in socio-ecological systems, as discussed below.

2.3.2 Resilience approaches to transformations

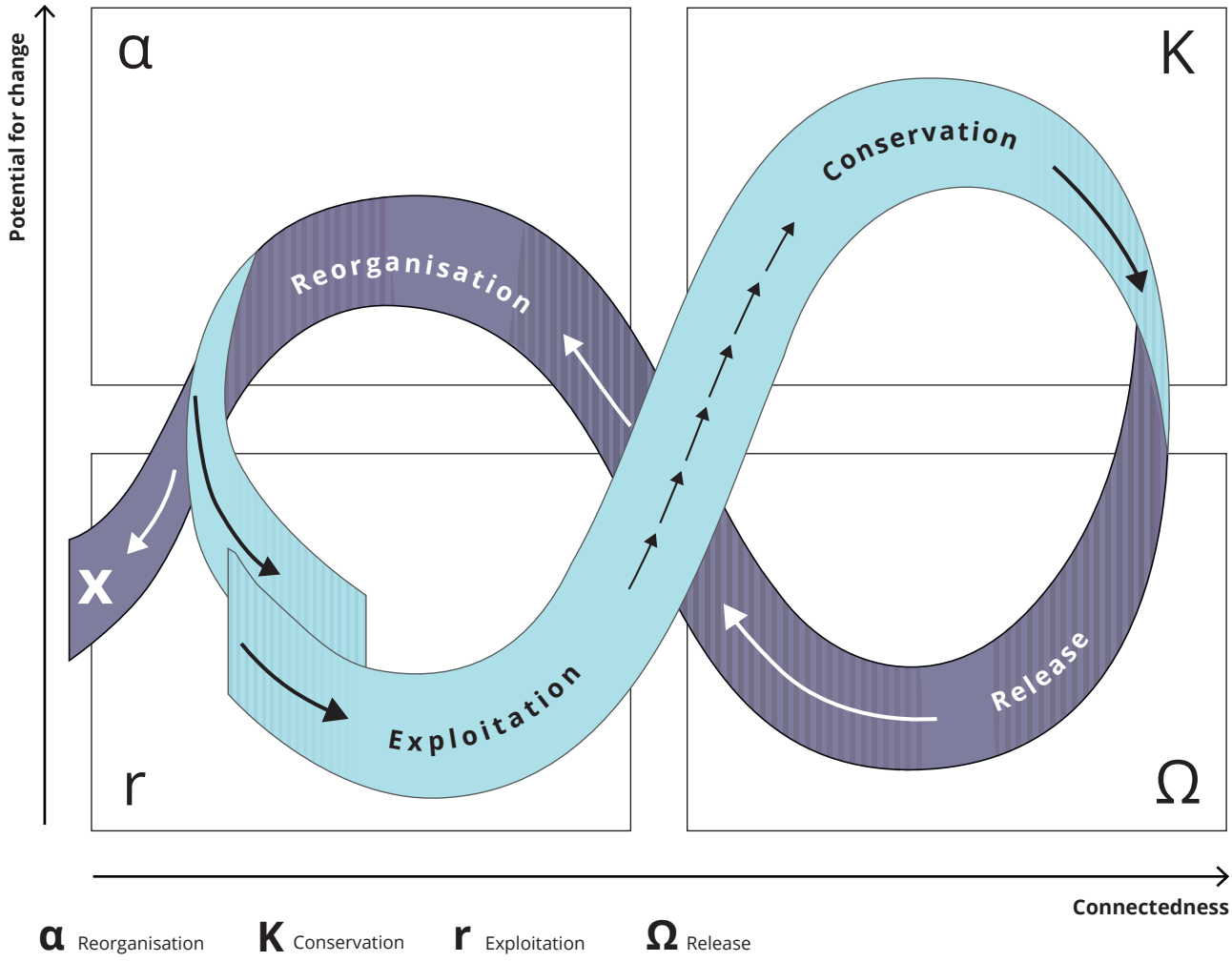
Resilience thinking focuses on the evolution of systems and the potential for unintended consequences, emphasising relations between systems and sub-systems that occur through flows and feedback, which in the case of society are increasingly linked to globalisation processes. As emphasised by Folke (2006), resilience approaches to transformation are less about planning and control and more about creating the conditions to prepare for and navigate transformations. Resilience thinking also draws attention to the role of innovation, learning and adaptive management — in other words, how humans co-evolve systems.

An important aspect of resilience approaches to transformation is its representation of system dynamics. Resilience is considered to be part of the entire transformation process, playing different roles at different times. For example, vested interests that try to maintain the oil economy may be supporting their own resilience, but the brittleness of the larger system, in this case a lack of resilience to climate change impacts, can lead to the collapse of the socio-ecological system in which it is embedded. The panarchy framework presented by Holling and Gunderson (2002) illustrates the links between social and ecological systems by emphasising four phases of the adaptive cycle and describing how they interact across scales (see Figure 2.1). These phases are exploitation (r), conservation (K), release (Ω) and reorganisation or renewal (α). In Figure 2.1, slowly changing situations are (somewhat counter-intuitively) represented by short arrows, while rapidly changing situations are depicted by long arrows. The framework also emphasises characteristics such as the potential for change (y-axis) and connectedness (x-axis).

A system may exist at any of the four stages of the cycle, but it is the reorganisation phase (α) that starts a process of growth, resource accumulation and storage. There is considerable uncertainty associated with this stage, as it is characterised by 'the greatest chance of unexpected forms of renewal as well as unexpected crises' (Holling and Gunderson, 2002). Moving into the exploitation phase (r), this is where opportunities and innovations expand, and where entrepreneurship is valued. As winners grow, expand and acquire more resources, connectedness increases and the adaptive cycle moves into the conservation stage (K). In this stage, the system eventually becomes less resilient and more vulnerable to surprise. If the socio-ecological system becomes too rigid, it may collapse in the face of random and external triggers. The release phase (Ω) of the adaptive cycle represents destruction, yet paves the way for the reorganisation phase (α). According to Holling and Gunderson (2002), the transition is characterised by an explosive increase in uncertainty and the potential for chaotic behaviour, which can potentially lead to new self-organising processes within the adaptive cycle. The resilient aspects of the emergent system are those components that can reorganise and help the socio-ecological system enter into a new cycle. When the stakes are high, a key question is whether or not society can collectively avoid the creative destruction/release phase (Ω) at a global level (associated with exceeding planetary boundaries) and instead allow some parts of socio-ecological systems to collapse and move into a state of renewal (α).

This framework represents the perspective of ecosystem ecologists, but there are argued to be many similarities and linkages with social systems (Westley et al., 2002). The 'front-loop' stage (i.e. from r to K) is slow and

Figure 2.1 The adaptive cycle



Source: Holling and Gunderson, 2002.

incremental, characterised by growth and accumulation and a tendency for predictability and certainty. The 'back-loop' stage (i.e. from Ω to α) is characterised by rapid change, unpredictability and uncertainty. The adaptive cycle as a whole is characterised by expanding and contracting resilience, with resilience decreasing as the cycle moves towards K and increasing as it moves into the back-loop stage and into a new cycle. Olsson et al. (2006) metaphorically refer to transformational change in socio-ecological systems as 'shooting the rapids', i.e. recognising that there is both risk and uncertainty in all change processes.

Based on an examination of real-world transformation processes, Olsson et al. (2006) identify three phases of socio-ecological transformations that can be experienced as either a regime shift between multiple stable states that eventually pass a threshold or a tipping point. The three phases are: preparing the system for change; navigating the transition; and building the resilience of the new governance regime.

These phases are linked by 'windows of opportunity', which describe an opening created by shocks or crises. Importantly, these windows of opportunity can also be used by those with vested interests in maintaining or strengthening the status quo or imposing regressive transformations, as often happens after disasters (Pelling and Dill, 2006). Many of the key concepts in the social sciences, such as power, conflict and agency, are not well represented in resilience approaches to transformation (Olsson et al., 2015).

2.3.3 Pathways approaches to transformations

Another set of approaches to transformations of socio-ecological systems have been collectively described as pathways approaches (Leach et al., 2010; Eisenhauer, 2016). Pathways approaches describe a range of alternative strategies or development trajectories to meet different visions and goals. It is recognised that there are multiple ways of meeting

these goals and acknowledging that some are likely to be prioritised, or else resisted and contested, depending on the social context (Scoones et al., 2015). The pathways approach is not distinct from the resilience approach, but rather captures the strategic decisions taken in different contexts that move society on to one pathway or another.

Eisenhauer (2016) identifies and describes four approaches to pathways research that have been used in climate change adaptation research: shared socio-economic pathways (SSPs); dynamic adaptive policy pathways (DSPPs); pathways to resilience; and social, technology and environmental pathways to sustainability (STEPS). Leach et al. (2007) use the notion of pathways to describe the ways that any particular system may change over time. A pathways approach is about more than simply recognising different options, 'it is also about the political process of building pathways which are currently hidden, obscured or suppressed' (Leach, 2010). Pathways are influenced by context, and it is recognised that political and institutional processes shape which visions and goals become dominant (Leach et al., 2007). Framings and narratives are viewed as important, as they prioritise and legitimise particular outcomes and goals, as well as understandings of systems dynamics.

Two strengths of pathways approaches are, first, their capacity to produce information that is context specific and hence more relevant, useful and usable for decision-makers; and, second, their consideration of non-linear change and uncertainty that calls for a process of ongoing monitoring and learning (Eisenhauer, 2016). Pathways approaches can also be used as metaphors for helping to visualise climate change adaptation options. A 'classic' view of adaptation pathways emphasises decision-making processes in situations of uncertainty and complexity, which often leads to incremental steps that may not be adaptive in the long run (Wise et al., 2014). Wise et al. (2014) propose conceptualising adaptation as pathways of interacting global changes and societal responses, with an emphasis on the social dimensions and transformative change, as opposed to an emphasis on technical aspects managed through incremental changes. This is not to say that incremental responses are not important; a pathways approach is iterative and responsive, similar to the concept of adaptive management. Climate-resilient pathways for sustainable development involve more than mitigating greenhouse gas emissions and adapting to experienced and projected impacts: they also involve pursuing development pathways consistent with equity, justice and sustainability, which often involves transformations (Denton et al., 2014).

2.3.4 Three spheres of transformation

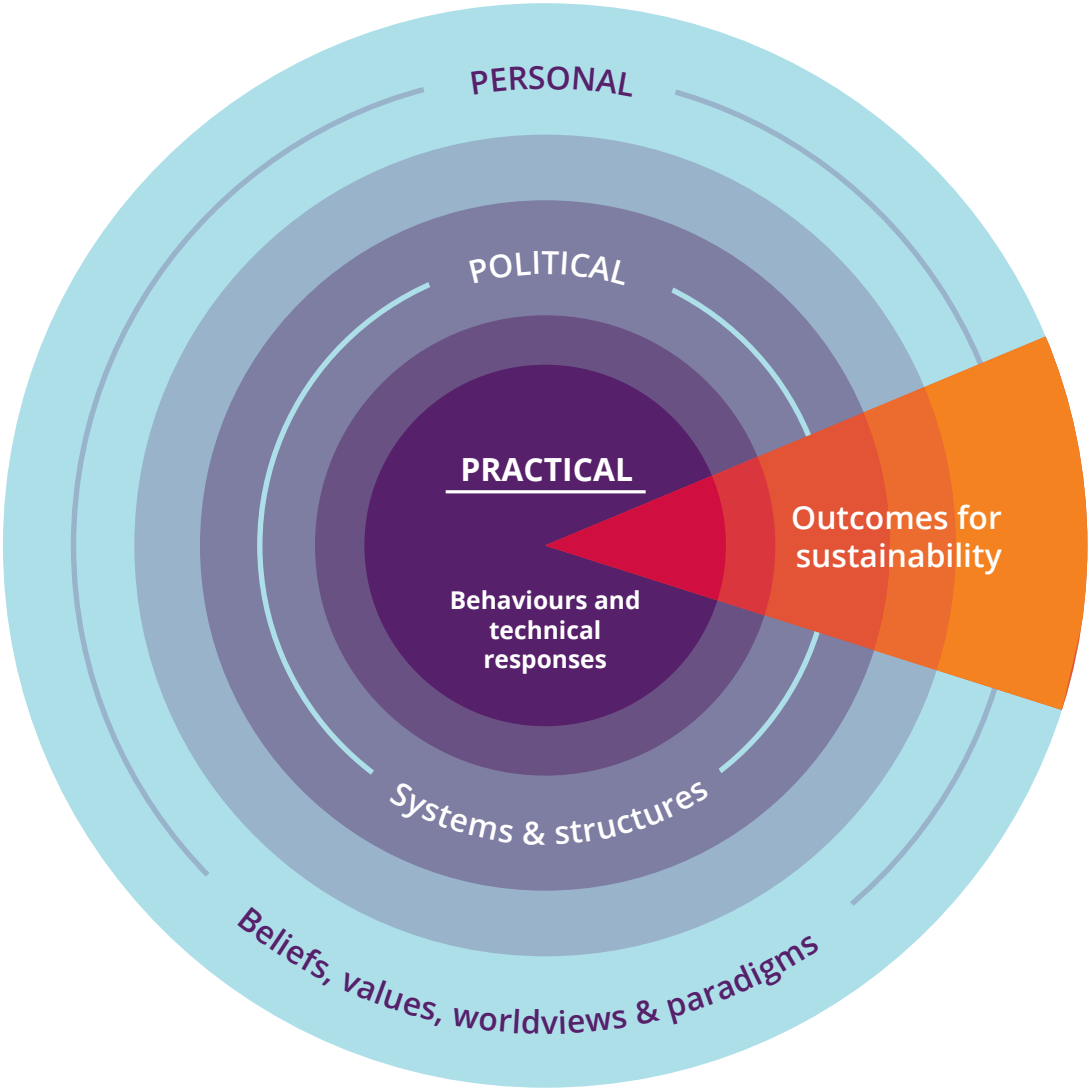
Resilience and pathways approaches are valuable ways of conceptualising transformations in socio-ecological systems, and they provide important insights for policy and planning. Importantly, they both recognise that transformation is a process operating at multiple spatial and temporal scales, where values and relationships between humans and the environment play a pivotal role in managing the biosphere and creating pathways to sustainability. Nevertheless, transformation can still come across as an abstract and confounding concept to researchers, policymakers and practitioners. The diversity, range and complexity of framings and approaches to transformation can indeed be difficult to grasp.

An heuristic device that captures transformation as significant changes in form, structure or meaning-making involves three interacting 'spheres' of transformation (O'Brien and Sygna, 2013; IPCC, 2014). These spheres — referred to as the practical, political and personal spheres of transformation — reference a variety of theoretical understandings of transitions and transformations, and emphasise the interplay between subjective and objective dimensions of socio-ecological change (Figure 2.2).

The practical sphere is at the core of transformation processes, and it includes many of the actions and interventions that are closely identified with sustainability outcomes: lower greenhouse gas emissions, more diverse ecosystems, more renewable energy, increased adaptive capacity, better early warning systems, reduced meat consumption, healthy fish populations, and so on. Transformations in the practical sphere are most often approached by enhancing knowledge and expertise, promoting innovation, improving management and nudging or changing behaviours. Such technical responses and behavioural changes can be measured and monitored, and although they may be difficult or challenging, they are nonetheless considered feasible. For example, transformations to low-carbon societies may involve lowering carbon dioxide (CO_2) emissions from cars and buses, encouraging cycling or the use of public transport, developing passive housing units that use little energy for heating or cooling, and so on.

Sustainability initiatives, including the SDGs, are usually focused on transformations in the practical sphere. Yet the success or failure of these initiatives (i.e. whether they in fact contribute to resilient, equitable and sustainable development pathways) often depends on social, political, economic and cultural systems and structures that influence, and in some cases define, the conditions for change. The political sphere is where the

Figure 2.2 The three spheres of transformation



Sources: O'Brien and Sygna, 2013; IPCC, 2014b.

decisions, rules, standards, regulations, agreements, incentives and priorities are discussed, negotiated, decided or imposed. It is here that some interests and agendas are prioritised over others, and where conflicts arise, particularly when collective action and political processes challenge vested interests and power relations that maintain systems and structures. Systems here may be characterised by inertia or lock-in, which is particularly the case if they functioned well in earlier contexts or served the needs of powerful interests.

It is in the political sphere that problems and solutions are identified and defined and where conflicts of interest may arise, particularly when structures and relationships are no longer accepted as immutable or 'given', or where alternatives emerge through new discourses and paradigms. For example, many European cities are now in the process of becoming more bicycle-friendly in an effort to improve urban living conditions and environmental quality. Among these, the city council of Oslo,

Norway, has the goal of making the city centre free of private cars by 2019. However, traffic principles and design standards established and maintained by a historically strong road lobby have created barriers to this vision. A new approach seeks to redefine the purpose of roads and establish new systems for bicycles, separate from cars and other traffic (Oslo, 2016). However, this is likely to create conflicts in the political sphere between the pro-bicycle city government and the national road directorate, among others. Social and cultural norms play an important role in defining the rules, regulations and institutions in the political sphere, which may eventually be challenged as new norms develop. Actions and inactions in the political sphere are influenced by the subjective values, worldviews and paradigms of different groups.

The personal sphere of transformation includes the subjective dimensions of transformation, including the individual and shared assumptions, beliefs, values, worldviews and paradigms that influence attitudes, actions and perceived options. As discussed by Schlitz et al. (2010), people's worldviews 'influence every aspect of how they understand and interact with the world around them'. This includes 'views' of systems and understandings of causality and human agency, as well as approaches to leadership and social change. These can often explain preferred strategies or approaches to transformations, including whether and which changes in the practical and political spheres are prioritised or ignored.

Transformations in the personal sphere can be powerful, especially if they open people or groups to new perspectives, including new ways of understanding human-environment relationships. Research by Schlitz et al. (2010) describes how the development of social consciousness corresponds to a series of transformations in worldview, moving from embedded to self-reflexive to engaged to collaborative to resonant. However, such transformations are often experiential and less likely to occur by convincing people with intellectual arguments.

Beliefs and worldviews implicitly influence the goals or objectives of systems, including who can and should benefit from them. Although many assume that systems and structures are fixed or given, the personal sphere draws attention to the social and cultural construction of rules, norms and behaviours that influence socio-ecological systems. It recognises that there are diverse types of knowledge and ways of knowing, and that different values may be prioritised in particular contexts.

Figure 2.3 depicts 12 leverage points for system changes discussed by Meadows (1999), which roughly map on to the three spheres of transformation:

- Changes in the practical sphere, represented by constants, parameters and numbers and the size of buffers relative to flows, are important, yet they are considered to have little leverage.
- Changes in the political sphere have increasingly greater leverage; these are represented by the structure of material stocks and flows, the length of delays relative to the rate of change, the strength of negative feedback loops, the reinforcement of positive feedback loops, the structure of information flows, the rules of the system, and the power to influence system structure.
- Changes associated with the personal sphere, which include the goals of the system and the mindset or paradigm from which the system arises, are considered by Meadows (1999) to have the greatest leverage points for systems change, exceeded only by the power to transcend paradigms. According to Meadows (1999), transcending paradigms involves staying flexible and open, recognising that all truths are partial and that there are uncertainties associated with all worldviews. Importantly, Meadows (1999) also points out that 'the higher the leverage point, the more the system will resist changing it.'

A key point is that all three spheres interact and are always influencing one another. Nonetheless, strategies and interventions that focus on greater leverage points may have a larger impact on outcomes. Whole-system goals such as global sustainability — or a 1.5 °C mean temperate target for global warming — can be powerful drivers of change. However, challenging the assumptions and beliefs underlying the worldviews and paradigms that perpetuate unsustainable practices may also be a powerful way to transform systems.

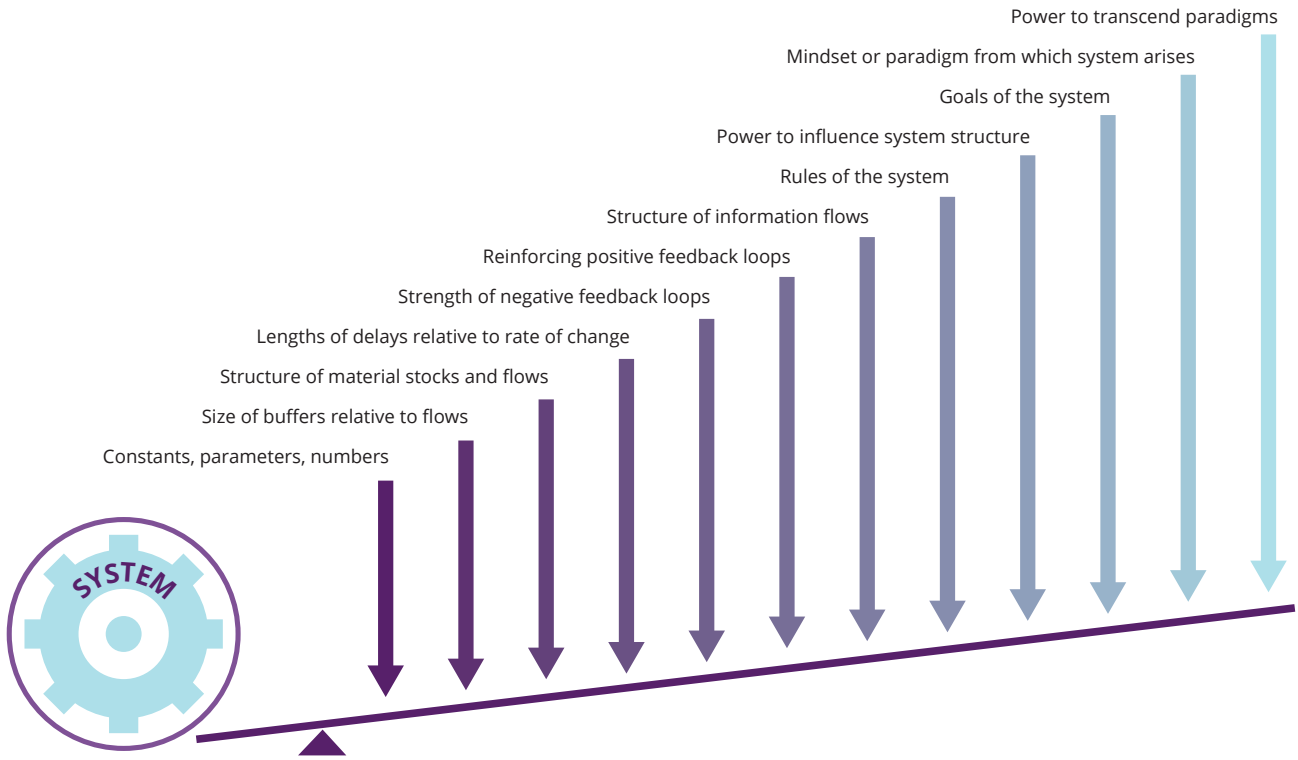
2.4 Core drivers and actors

What or who drives transformations in socio-ecological systems? Resilience approaches, pathways approaches and numerous other frameworks draw attention to a variety of potential drivers of transformation.

2.4.1 Crises as accelerators of transformation

Transformational change often takes time, but it can arguably be accelerated by crises or extreme events,

Figure 2.3 Leverage points for systems change



Source: Based on Meadows, 1999.

or what is referred to in the adaptive cycle as the release phase (Ω) (Figure 2.1). This includes all types of transformations, including those that are considered negative or harmful.

Kates et al. (2012) consider external drivers to be 'focusing events' which, when combined with local leadership, can in some cases be important in initiating transformational adaptation. Internal drivers include 'effective adaptive institutions combined with public values and attitudes and the availability of understandable and socially acceptable options, along with incentives and resources for action and leadership' (Kates et al., 2012). From an evolutionary perspective, 'the combination of crisis, communication and collaboration is a powerful generator of emergent social novelty. New social wholes are greater than the sum of their parts' (Hetherington and Reid, 2010). While crises provide opportunities for positive change, they also introduce the risk of regressive change, as people and organisations tend to contract and protect their own short-term interests when their security is threatened.

2.4.2 Leadership

Much attention has been paid to innovators, activists, champions, thought leaders and change agents as drivers of transformations, and the leadership literature is full of theories and anecdotes about human agency and the role of individuals in systems change (Senge, 1990). Although leadership is often cited as a critical factor in driving change, it is the quality of engagement with systemic change that is often decisive.

Westley et al. (2013) suggest that traditional notions of leadership cannot explain transformations in complex systems characterised by emergent properties, and they argue that a new framework is needed. They discuss how institutional entrepreneurs can influence each stage of transformation processes, whereby each stage calls for different strategies and interventions. In particular, they draw attention to the skills needed to engage with systems change, which include responding to and working with opportunities and resource flows. Within the four stages of the adaptive cycle (exploitation, conservation, release and reorganisation),

the opportunity context is influenced by two primary drivers: 'the diversity and multiplicity of organisational forms, and the degrees of institutionalisation' (Westley et al., 2013). They emphasise that the more established the rules and institutions, the less the opportunity for change, and they point to the need for institutional entrepreneurs to be attuned to the evolving contexts of systems.

The mindset or worldview from which individuals, groups and organisations engage with systems change is thus a critical factor in transformations of socio-ecological systems. The ability and degree to which any leader or organisation can focus and extend awareness and attention to the complex dynamics of socio-ecological systems influences how the system is viewed, understandings of causality and visions of the future. In discussing worldview transformations, Schlitz et al. (2010) emphasise the importance of 'cognitive flexibility, comfort with unfamiliarity, appreciation of diverse perspectives, agility in the face of rapidly changing circumstances, ability to hold multiple perspectives simultaneously, and a capacity for discernment that relies equally on intellect and intuition'.

While there is considerable attention given to the types of actors and institutions that may lead transformations in socio-ecological systems, the drivers of change may be less about the people and institutions and more about the conditions in which transformative changes can flourish. Conditions for transformative change may, for example, include collaboration, empowerment, creativity and flexibility, which together can foster the connections and integration that are characteristic of the 'back loop' of the adaptive cycle and which can generate sustainable pathways for socio-ecological systems.

2.4.3 Governance

Governance plays an important role in transformations to sustainability. Drawing on research from the Earth System Governance project, Patterson and colleagues (2016) explore how 'the interrelated and increasingly integrated system of formal and informal rules, rule-making systems, and actor-networks at all levels of human society (from local to global)' can contribute to transformations. This includes governance **for** transformation, governance **of** transformation, and transformations **in** governance.

Socio-ecological transformations are often approached as global issues, in recognition that problems such as climate change are collective action problems in which the success depends on the aggregate outcomes. Consequently, international institutions and agreements are considered important, both to provide a framework for action and to support the incentives, monitoring and reporting mechanisms considered necessary for successful transformations within the context of the Anthropocene. However, Lövbrand et al. (2009) question the naturalisation of a particular approach to governmentality that emerges from an Earth system perspective — one that ironically 'both challenges and reproduces Enlightenment promise of human self-realisation, autonomy and control.'

Biermann et al. (2016) argue that the Anthropocene concept risks being framed in a way that is too global and monolithic, masking diversity and differences in conditions and impacts. To have societal and policy relevance, the notion of the Anthropocene needs to be scaled down to include context-dependent, localised and social aspects. At the same time, local and national governance alone will not be adequate — high levels of global connectivity require strong global institutions and intergovernmental cooperation. Until now research has been divided between these levels without much attention to integration (Biermann et al., 2016).

Integration of governance across scales is considered critical to the management of socio-ecological systems. The move away from governing human and natural systems separately has led to a greater focus on flexible and open institutions and multi-level governance systems that contribute to learning and adaptive governance (Folke et al., 2009). Adaptive governance of socio-ecological systems is considered necessary because the management of ecosystems and landscapes is not amenable to planning and control by a central organisation, such as a national government. Folke et al. (2005) identify four interacting aspects in adaptive governance:

1. building knowledge and understanding of resource and ecosystem dynamics;

2. feeding ecological knowledge into adaptive management practices;

3. supporting flexible institutions and multi-level governance systems;

4. dealing with external perturbations, uncertainty and surprise.

Research on adaptive governance recognises that the transformation of entire governance regimes is 'related to the scale at which the crisis most clearly manifests itself and how it is perceived in relation to the scope of change possible' (Olsson et al., 2006). Through five regional case studies that focus on the social features

of governance systems, Olsson et al. (2006) found that ecological crises and social change at one scale can trigger a transformation in governance at another scale. Key factors supporting such transformations include perception and meaning, network configurations, social coordination, institutional arrangements and organisational structures contributing to adaptive governance. Shadow networks, which operate outside conventional decision-making arenas, and leadership that can mobilise broad support for change as key to successful transformation were seen as critical to the success of adaptive governance (Olsson et al., 2006).

Socio-ecological systems are considered manageable, within limits, through polycentric forms of governance, with polycentric referring to multiple and independent centres of decision-making that foster innovation, learning, adaptation and cooperation (Ostrom, 2014). Most research assessments, including IPCC and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), consider the state to be the appropriate level for governance of environmental challenges (Biermann et al., 2016). Yet other levels, such as urban areas, are also important sources of governance, in relation to both the causes of global environmental change and the solutions. Loorbach (2014) calls for meta-governance through institutions that are able to deal with uncertainty, surprises and diversity and through institutions that are able to transform themselves.

2.4.4 Barriers to transformation

Many of the barriers to transformation reside in the political sphere, where decisions, behaviours and social practices are often systematically 'locked-in' by current structures and regimes. The main barriers to transformation in socio-ecological systems occur at the levels of both individuals and institutions, which are considered to have inadequate information, vested interests and an inability to overcome inertia. The power to transform systems is frequently seen to lie in market instruments including taxes, trading schemes, investments and insurance schemes, which are considered dependent upon political will and leadership. The pursuit of regional and international agreements and better rules and regulations is also considered important in creating a 'level playing field' for market-based solutions.

Path dependency of investments, including in infrastructure, is often presented as a barrier to transformative change. However, it has also been argued that 'lock-in' is a myth (Essebo, 2013).

2.5 Empirical examples

Conceptualisations of transformations in socio-ecological systems can be best illustrated through empirical case studies (Olsson et al., 2006; Leach et al., 2007). There are many examples of positive change taking place around the world. Bennett et al. (2016) have collected and analysed a database of over 100 current examples of experiments, good practice and innovations that may serve as 'seeds of a good Anthropocene.' Recognising that a socially, ecologically and economically desirable world is likely to differ quite radically from the present, they document examples that cover agroecology, green urbanism, future knowledge, fair futures, sustainable futures and urban transformations. Although cases such as the German *Energiewende* provide promising examples of large-scale transformations of socio-technical systems (Geels et al., 2016c), there are (as yet) relatively few empirical examples of successful large-scale transformations of socio-ecological systems towards sustainability. This contrasts with mounting evidence of negative socio-ecological transformations, particularly in Arctic regions (Arctic Council, 2016). It is nonetheless possible to identify some of the contexts in which conditions are emerging to support transformative change.

2.5.1 Urban transformations

There is perhaps no other context in which transformations are as visible and necessary as in urban areas. With over 50 % of the world's population located in cities, and with ecological footprints of urban areas extending far beyond the physical boundaries of cities, urban transformations are considered a prime focus for sustainability. It has been argued that increasing the city's capacity to meet the growing challenges of sustainability is, to a large extent, dependent on developing a holistic governance approach, whereby the city is understood as a dynamically interacting socio-ecological system (Frantzeskaki and Tilie, 2014).

The principles of socio-ecological systems can be seen in urban planning and design. For example, an urban development project in Stockholm uses the concept of buffering capacity and potential for renewal to explore how social and ecological systems interact and how design solutions such as 'green arteries', 'active ground' and 'performative buildings' can contribute to socio-ecological resilience in the built environment (Bendt et al., 2013). Such approaches promote alternative models for urban living, which can be considered a form of resistance to the privatisation of public spaces.

Indeed, public spaces can be used to leverage disruptive changes in urban environments, as shown through three cases in New York City, presented by Radywyl and Biggs (2013). Drawing on resilience theory, these authors explore the conditions and mechanisms through which commons practices develop and how they influence urban transformations. They suggest that urban commons can be important vehicles for transformation because they are linked to behaviours, cultures and institutions that are consistent with sustainability. Such practices may scale horizontally and vertically to weaken or undermine the resilience of existing urban systems (Radywyl and Biggs, 2013). Overall, increased linkages between strategies, projects and actors, particularly the active involvement and engagement of local citizens, have been identified as a key factor in urban transformations to sustainability (Meyer et al., 2012; Wardekker et al., 2010; Ward et al., 2013).

Innovative solutions to complex challenges are increasingly explored systemically through experimental laboratories, such as 'Living Labs' and 'Urban Transitions Labs', where innovative solutions are tested out to see if they work and can be scaled up into larger systems (McCormick and Kiss, 2015; Nevens et al., 2013). The projects typically involve collaboration among governments, private corporations, researchers and the public. While many of the solutions that are tested are technical (related to information technologies), a key focus is on the barriers and enablers for systemic change.

Green spaces and the commons are considered key components of resilient urban socio-ecological systems (Schewenius et al., 2014). In addition, urban agricultural initiatives such as hoop houses, greenhouses, guerrilla gardening, food forests and urban gardens, as well as alternative urban food economies such as farmer's markets, cooperatives and local food sheds, provide examples of the interplay among the practical, political and personal spheres of transformations in socio-ecological systems. For example, community gardens — areas that are open to anyone at all times and managed by various interest groups — can foster learning and the development of a sense of place while supporting biodiversity conservation (Bendt et al., 2013). Management by locals has been shown to contribute to cultural integration and an increased capacity to deal with changes and surprises, including economic shocks. A study of 27 urban gardening initiatives in Barcelona by Camps-Calvet et al. (2015) describes how they can nurture social and ecological diversity, generate and transmit local ecological knowledge, and create opportunities for collective action and self-organisation.

2.5.2 Food-water-energy nexus

The food-water-energy nexus presents an excellent opportunity for exploring transformations in socio-ecological systems. The 'nexus' approach recognises that food, water and energy are closely interrelated and cannot be addressed through piecemeal or fragmented policies and actions (Mohtar and Daher, 2012). For example, the nexus approach has been used to explore the role of ecosystem services and their relationship to food, water and energy security in the Himalayas (ICIMOD, 2012; Rasul, 2014). It has also been used to examine agricultural energy efficiency in India, recognising that it is integrated within a larger food-water-energy nexus and considering the policy implications (Swain and Charnoz, 2012).

Research on food-water-energy systems increasingly centres on urban environments as sites of transformative change. For example, Treemore-Spears et al. (2016) analysed two post-industrial urban settings in the United States (Detroit, Michigan, and Baltimore, Maryland) as compelling sites for environmental, economic and social sustainability in relation to the food-water-energy nexus. Iwaniec (2016) analysed a transdisciplinary, co-designed international initiative, P-FUTURES, effort to ensure urban food and water security, with a focus on phosphorus access and waste.

Climate smart agriculture (CSA) and permaculture represent two additional approaches to transformations of socio-ecological systems; each may be more resonant with particular values, worldviews and development paradigms. CSA has been defined by the United Nations Food and Agriculture Organization (FAO) as 'an approach that helps to guide actions needed to transform and reorient agricultural systems to effectively support development and ensure food security in a changing climate' (FAO, 2016). The CSA approach involves the three objectives of sustainably increasing productivity and income; adapting to climate change; and reducing greenhouse gas emissions. The FAO (2014) describes 10 CSA success stories from around the world, recognising the need for diverse solutions to transform agricultural sectors (crops, livestock, forestry, fisheries) to feed a growing global population while reducing poverty and serving as a basis for economic growth, without degrading the natural resource base.

Drawing on 17 CSA case studies from Africa, Nyasimi et al. (2014) describe the complex, interrelated factors that, if scaled-up and more widely adopted, could transform socio-ecological systems in Africa. For example, the Humbo Assisted Natural Regeneration project in Ethiopia engages the local community in restoring biologically diverse natural forest and

investing in food and water security. However, the study acknowledges that, despite promising signs, 'adoption will continue to be low and impact will remain limited if governments do not invest in scaling-up projects and knowledge dissemination' (Nyasimi et al., 2014). The scaling-up process shifts attention from the practical to the political sphere of transformation and draws attention to the diversity of values, beliefs and paradigms regarding agricultural practices and sustainability.

Permaculture represents an alternative paradigm for food provision. It consists of a system of socio-ecological design principles that serve to create 'consciously designed landscapes which mimic the patterns and relationships found in nature, while yielding an abundance of food, fibre and energy for provision of local needs' (Holmgren, 2002). While permaculture lacks a central, institutionalised definition, the definitions, principles and ethics provided by the Australians Bill Mollison and David Holmgren in *Permaculture One* (Mollison and Holmgren, 1981) continue to serve as the central framework. It provides a holistic approach that considers agricultural systems as socio-ecological systems and follows three central ethics: people care, fair shares and earth care. Intrinsic to the interdisciplinary philosophy of permaculture is recognition of the connection between food, water and energy.

Brawner (2015) explores the transformational potential of permaculture design and its emergence as a socio-ecological paradigm that is becoming increasingly relevant. Studying a permaculture site in rural Shipka, Bulgaria, she describes how permaculture education incorporates ecological language and systems thinking, which emphasises diverse ways of knowing, the absence of a knowledge divide between experts and laypersons, and the integration of 'agent-gardeners.' Brawner concludes by asserting that the unique potential of permaculture lies in its inclusion of the social and its adaptability to changing socio-political contexts. Leahy (2013) describes how subsistence farmers participating in the Chikukwa project in Zimbabwe integrate a permaculture framework with their indigenous knowledge to combat food insecurity, restore vegetation, protect watersheds and promote conflict resolution and female empowerment. The project uses a socio-ecological model that emphasises local commons-based governance.

A key point here is that collaborative projects and networks at the local level can be springboards for socio-ecological transformations. Permaculture practices are also spreading across college and university campuses in the United States (Pothukuchi and Molnar, 2015). Skanavis and Manolas (2015) analyse how the practice of implementing permaculture and other sustainability projects directly on sites of higher education fosters civic ecology as well as better understandings of the integral linkages between food-water-energy systems and social systems. The most successful example is at the University of Massachusetts Amherst (Harb, 2011; Bentzin et al., 2014). Other examples include the University at Buffalo (Mosher et al., 2015), Cornell University and the University of Maryland, Baltimore County. In these cases, permaculture acts as one part of campus sustainability programmes that involve students as active agents of change. Processes and practices that transform relationships with the environment can be considered powerful catalysts for the paradigmatic shifts needed to engage people with transformations in socio-ecological systems.

2.6 Strengths and weaknesses of the approach

Transformations are essential to the global sustainability of socio-ecological systems, and research frameworks and approaches from this field have many strengths. Key among these is that the socio-ecological approach takes a big-picture, systems perspective that integrates humans with nature. Moreover, it can help to identify where sustainability solutions may lead to unintended environmental and social consequences. The idea of deliberate, desirable transformations in socio-ecological systems is both appealing and empowering, and it draws attention to the ways that small changes can lead to large effects. Its focus on interactions across multiple systems and scales and its acknowledgment of complexity and the potential for emergent properties offers a more holistic, integrated understanding of systemic change.

A weakness of the socio-ecological systems perspective is that it lacks a coherent framework for bringing together the subjective attributes of individuals and groups with objectively measurable changes in behaviours and systems. This perspective often glosses over the role of power, politics and vested interests in either blocking or slowing transformational change, and instead seeks to reform or transition systems, including capitalism, rather than consider alternatives or radical changes (Pelling, 2011). Leadership is frequently attributed to individuals who hold power or influence at different levels of society, whether through political position, strategic agency or entrepreneurial activity. The power of social movements, civil society and other types of collective action is sometimes considered trivial or is ignored in research on socio-ecological transformations.

Although there is recognition that there will be both winners and losers in transformation processes, little attention has been paid to how this links to the global political economy and transparency surrounding the question of 'who decides' on the solutions to be prioritised (Swyngedouw, 2010; O'Brien and Selboe, 2015b). Studies of equity, ethics, social justice, governmentality, deliberate democracy and other social science research can make important contributions to understanding the political dynamics of transformations in socio-ecological systems. This includes a focus on compensation for loss and damages, the legal frameworks for migrants and displaced populations, and issues of intergenerational justice.

As an integrative framework, a socio-ecological systems approach does not provide a very wide opening for the social sciences and humanities, particularly those that take critical and interpretivist approaches that may challenge the assumptions of the models and frameworks for analysis. In fact, much important research on social change from the social sciences and humanities is ignored or excluded in contemporary approaches to transformations in socio-ecological systems, and efforts to link environment and society are often overly deterministic, downplaying the role of conflict and antagonisms (Stirling, 2015). Research programmes such as Future Earth offer an opportunity to address these weaknesses, but their success will depend on finding suitable frameworks and generating a language for understanding transformations from multiple perspectives.

If the full range of actions and interactions within and among all three spheres of transformation are not considered, it is likely that a techno-managerial approach to transformations will dominate over critical and reflexive approaches that challenge dominant systems and question prevailing worldviews and paradigms. A socio-ecological framework, nonetheless, has the potential to expand its coverage of the 'socio', and in doing so it may open up alternative strategies and approaches to support transformations to sustainability.

2.7 Knowledge for transformation of socio-ecological systems

2.7.1 Understanding the benefits, costs and risks of transformational activities

To promote transformations that are equitable, ethical and sustainable, there is a need for reflexive frameworks that link experiential and cultural aspects of transformative change to transformations in the political and practical spheres. As more and more individuals, groups and institutions engage with solutions to global challenges, it is becoming more and more important to assess the impacts of transformative responses on socio-ecological systems. Recognising that not every solution will be equally beneficial, and that some may be dangerous to the lives and livelihoods of others, it is necessary to critically assess and explore pathways and possibilities for alternative futures. The risks of 'solutions' having negative impacts on others and on future generations need to be assessed, and the beliefs, values and interests that are behind these solutions need to be made transparent.

2.7.2 Early warning signals for positive social change

There are currently very few data and little evidence on how to achieve transformations at the rate, magnitude, scale and penetration called for by global change science. Policy mandates such as the Paris Agreement aim to limit climate change to 1.5 °C and the SDGs provide numerous targets and indicators, but the evidence for transformations often appears only in hindsight. To collect data for anticipating transformations in socio-ecological systems, there is a need to identify some 'early warning signals' for positive social change (Bennett et al., 2016). This might include data on changing worldviews and values among young people, data on increased participation in sharing economies, metrics of the growth and expansion of circular economies, monitoring of investment patterns, analysis of how environmental issues are represented in popular culture or changes in social norms (Nyborg et al., 2016).

2.7.3 Identifying frameworks for collective engagement

It is generally assumed that everyone is seeing the same system, that humans are rational actors, and that everyone has a stake in 'our common future'. Actionable frameworks that draw attention to the role of cognition, morals, aesthetics and art, emotions, values, and so on, can help to generate collective engagement with systemic change processes. Although reflexivity and foresight is still not commonplace in society, it is possible to work with a diversity of perspectives, frameworks and approaches in pursuing transformations to sustainability in socio-ecological systems.

2.7.4 Identifying effective modes of governance

One challenge for transformations of socio-ecological systems is to integrate local and regional governance

solutions within a global framework, so that potential alliances can flourish and networks of cities can drive global transformations. 'Clumsy solutions' to environmental problems recognise that a variety of solutions are needed to appeal to different cultural values, whether hierarchical, individualistic or egalitarian (Verweij and Thompson, 2006). Hybrid approaches and flexible institutions are considered to be more capable of dealing with rapid change and uncertainty. Complexity theory and insights on self-organising systems suggest that transformations of socio-ecological systems can emerge through collaboration across different spatial scales, social groups, institutions and objectives (Urry, 2005). This requires not only a combination of top-down and bottom-up approaches to governance, but also inside-out approaches that transform some of the key assumptions that maintain unsustainable systems.

2.7.5 Deepening understanding of societal change processes

There is a tremendous amount of knowledge about transformations in socio-ecological systems, including many case studies that have been analysed and assessed through diverse analytical frameworks, including resilience and pathways approaches. However, questions still remain about the sheer ability and potential for society to transform at the rate, scale and speed that is called for to avoid the negative impacts of environmental and social change, including dangerous climate change. Part of this can be attributed to the particular 'theories of change' employed in global change research, which include a general lack of attention to:

- politics and power and historical materialism;
- how individual and shared beliefs, values and worldviews influence understandings of, and engagement with, systems change;
- how paradigms influence the questions that are asked and the methods that are considered legitimate in answering them;
- evolutionary dimensions of cultural and social change.

This raises a key question for complexity theory and systems thinking, namely the role of intentionality and consciousness in collective transformation processes and the role of creative, empowered and reflexive individuals in systemic change. As Meadows (1999) points out, the power to add to, change, evolve or self-organise the structure of a system is a potent driver of systems change: 'The ability to self-organise is the strongest form of system resilience. A system that can evolve can survive almost any change, by changing itself.'

3 Socio-technical transitions to sustainability

Frank Willem Geels (University of Manchester)

3.1 Introduction

This chapter focuses on transitions in socio-technical systems, which enable the fulfilment of societal functions such as mobility, feeding, power, heating and shelter. Energy, transport and agro-food systems account for 70-80 % of global environmental problems in terms of lifecycle impacts (Tukker et al., 2010). Addressing global environmental problems therefore requires major changes in these systems, which are conceptualised as socio-technical transitions, as will be explained below.

Although research on socio-technical transitions emerged within the field of innovation studies, it has been further developed and elaborated in various directions within the Sustainability Transitions Research Network (STRN), which was officially created in 2009 (http://www.transitionsnetwork.org/). This community organises annual conferences, is linked to the journal *Environmental Innovation and Societal Transition* and has a regular newsletter and active mailing list. Currently, more than 1 000 researchers are members of STRN, with the majority from Europe. The 'multi-level perspective' has become a prominent analytical framework in this community, although other frameworks such as 'technological innovation systems' (TIS) and 'transition management' (TM) also form active research lines and are addressed in this chapter.

While innovation (in its various forms) is crucial for socio-technical transitions, it is understood to co-evolve with many other dimensions. This diversity is apparent in the following list of themes from the STRN research manifesto:

- governance, power and politics;
- implementation strategies for managing transitions;
- civil society, culture and social movements in transitions;
- the role of firms and industries in transitions;
- sustainable consumption — transitions in practice and everyday life;
- the geography of transitions.

Many of these themes will be addressed in this report, although not in equal depth.

3.2 Conceptual background and assumptions

3.2.1 Disciplinary background and assumptions

The socio-technical transitions approach draws on insights from several disciplines. The following points derive from evolutionary economics:

- Economic evolution at the sectoral level has a punctuated equilibrium dynamic. Industries (i.e. populations of firms) experience long periods of stability and incremental change, punctuated by relatively short periods of disruption and 'waves of creative destruction' (Schumpeter, 1939). Technological discontinuities and disruptive innovations are important drivers for this punctuation, although the literature also increasingly emphasises the discontinuous effects of business model innovation (Bolton and Hannon, 2016) and new uses (Schot et al., 2016).
- In contrast to mainstream economics, firms (and other actors) are not conceptualised as fully rational, self-interested profit (or utility) maximisers. Instead, Neo-Schumpeterian economists (Nelson and Winter, 1982; Dosi, 1982) emphasise the importance of routines, searches (within a 'knowledge space'), learning and capabilities, which differ between firms within an industry and thus lead to variation in products and services. The market then acts as a selection environment in which products with the highest fit with consumer requirements survive. So, change results from interactions between variation and selection.

- Evolutionary economists make a distinction between incremental innovation, which are gradual improvements in existing technologies and practices, and radical innovation, which refers to novelties that deviate substantially from the mainstream (e.g. a new knowledge base or business model). Incremental innovation is normal, and delivered in the context of stable 'technological regimes', which are routines, knowledge and capabilities shared by incumbent actors in a sector. Radical innovations are rare, emerging in protected niches that are separated from the main population (Schot and Geels, 2007).

From the field of innovation studies (and sociology of technology) the following insights are relevant:

- Innovation is a social process, based on interactions between multiple actors (engineers, firms, policymakers, standardisation organisations, non-governmental organisations (NGOs), etc.) with different views and interests. Social constructivists of technology (Bijker et al., 1987) criticise the 'linear model' of technical change, which assumes that science and technology emerge because of their own internal logic and subsequently 'impact' society (as in a 'billiard ball model'). They replace this with notions of co-evolution of technology and society based on continuous interactions between many actors throughout periods of invention, innovation and diffusion.

- The diffusion of new radical innovations and systems into markets and society is seen as a contested and negotiated process (Deuten et al., 1997), which includes adjustments in business, user, policy and cultural environments.

- Technology is pervasive in modern societies, as most aspects of daily life are designed and regulated. This includes not just electricity and transport, but also water, agro-food, waste and buildings. The American philosopher Mumford (1934) suggested that we live in a 'technotope' or human-built world (Hughes, 2004). Sustainability transitions are therefore socio-technical, since they inevitably involve both changes in technologies and changes in markets, cultural meaning, policy and politics.

The following assumptions from institutional theory inform the understanding of socio-technical transitions:

- Actors are not entirely 'free'. Instead, their preferences, ideas, interests and identities are shaped by different kinds of institutions: regulative, normative and cultural-cognitive (Powell and DiMaggio, 1991; Scott, 1995).

- Transitions inevitably require adjustments in institutions. Cultural-cognitive institutions are often the most difficult to change.

- Institutional change often includes power struggles between vested interests and new entrants (Levy and Egan, 2003; Kern, 2011).

Based on these insights, socio-technical transitions have the following characteristics:

1. Transitions are co-evolutionary processes that require multiple changes in socio-technical systems. Transitions involve both the development of technical innovations and their use in societal application domains. This 'use' includes adoption by consumers (markets and integration into user practices) and broader processes of societal embedding, which may require changes in regulations, markets, infrastructures and cultural discourses.

2. Transitions are multi-actor processes, entailing interactions between businesses, different types of users, scientific communities, policymakers, social movements and special interest groups.

3. Transitions are radical shifts from one system to another. The term 'radical' refers to the scope of change, not to its speed. Radical innovations may be sudden and lead to creative destruction, but they can also be slow, proceeding in a step-wise fashion.

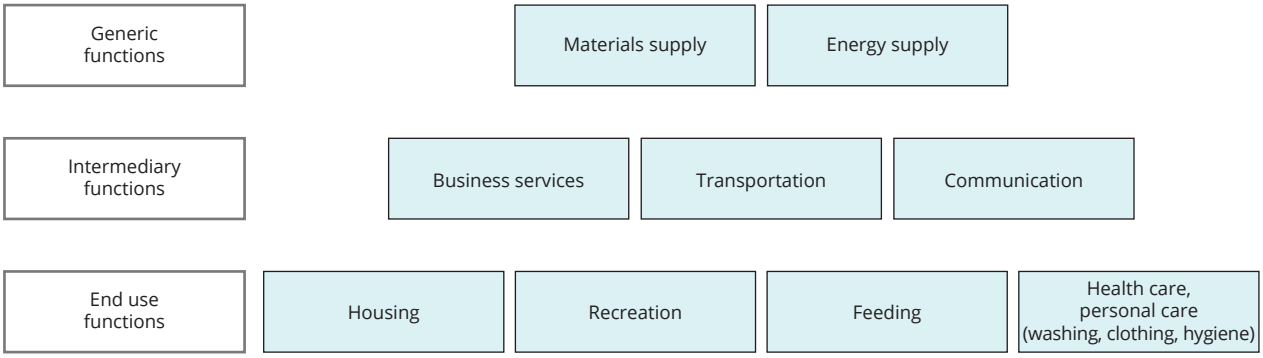
4. Transitions are often long-term processes (40-50 years). While breakthroughs may be relatively fast (e.g. 10 years), the preceding innovation journeys through which new socio-technical systems gradually emerge usually take much longer (20-30 years).

3.2.2 System focus

Socio-technical transitions are about changes in the way societal functions are fulfilled (Figure 3.1). Societal functions with large environmental implications are transport, housing, feeding and energy supply.

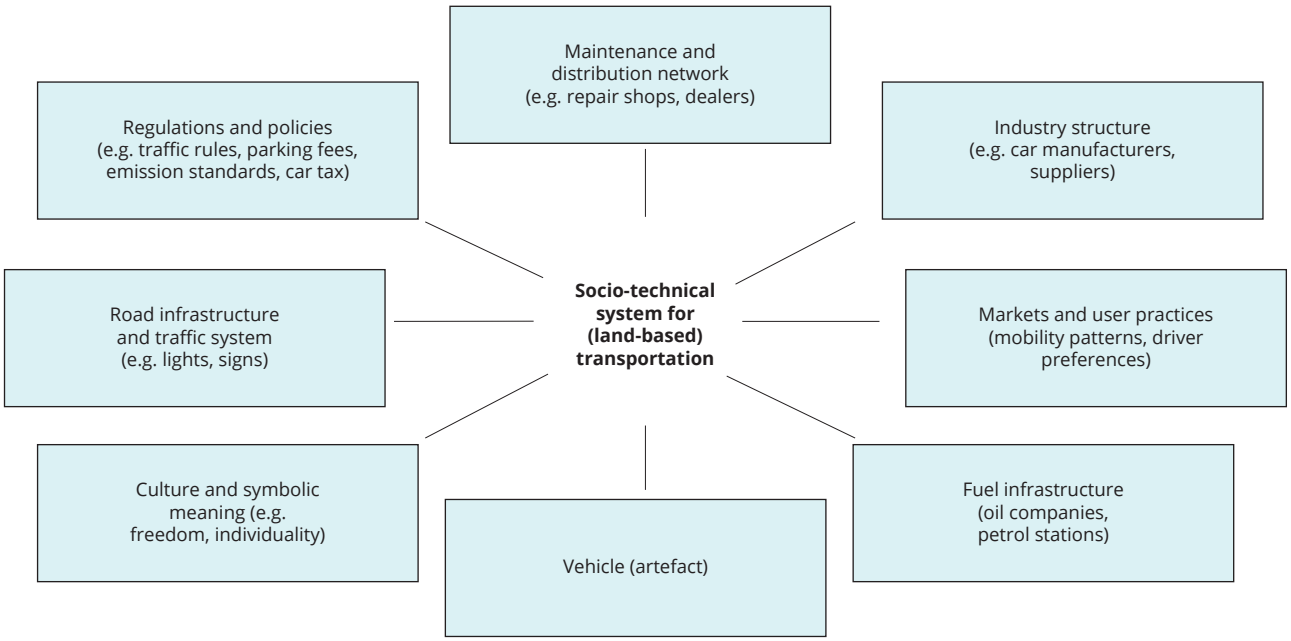
Societal functions are fulfilled through socio-technical systems, i.e. configurations of interacting elements. Figure 3.2 provides an example for the dominant automotive transport system. This conceptualisation means that socio-technical transitions are about both production and consumption (as well as culture, politics and infrastructure).

Figure 3.1 Societal functions as the level at which socio-technical transitions occur



Source: Weterings et al., 1997.

Figure 3.2 Example of socio-technical system for (land-based) transport



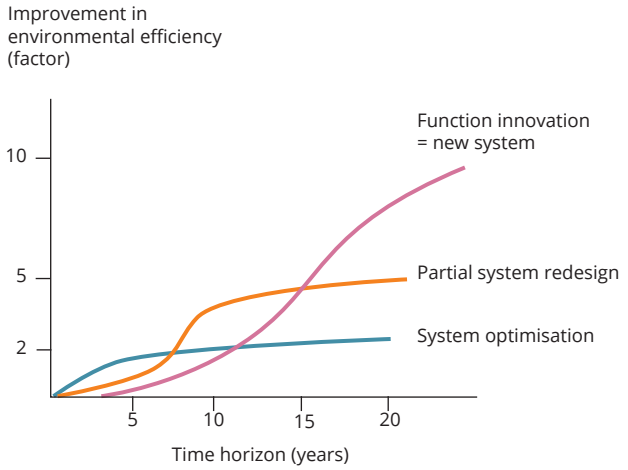
Source: Geels, 2005b.

Many empirical studies in the transitions community have focused on transport and electricity. There are also studies, however, of agro-food, heating, buildings, water and waste management.

Many studies focus on climate change. Other environmental problems (water pollution, air pollution, chemicals, biodiversity loss, acidification) tend to receive less attention.

The basic assumption is that addressing persistent environmental problems requires large improvements in environmental efficiency, which, in turn, requires transitions to new socio-technical systems (Figure 3.3). Incremental changes (system optimisation) and partial system change may offer some improvement in the short- to medium-term. However, large improvements require shifts to new systems.

Figure 3.3 The need for socio-technical transitions



Source: Weterings et al., 1997.

Figure 3.4 Phases and orientations in environmental policies

A	**Reactive**	**Receptive**	**Constructive**	**Pro-active**
B	End-of-pipe	Process	Product	System
C	Specialists	Managers	Sector	Society
D	Minimisation	Optimisation	Acceleration	Vision

A Response phase

B Focus of attention

C Main actors

D Driving philosophy

Source: UN, 1999.

System transitions can be seen as the next step in environmental policy thinking, which has progressed through several steps in the last 30 years (Smith et al., 2010):

- end-of-pipe solutions (e.g. catalytic converters in cars) in response to local environmental problems in the 1970s and 1980s;
- cleaner production by redesigning manufacturing processes in the 1980s and 1990s (e.g. closing material loops, waste reduction and efficiency improvements);
- eco-innovation and green technologies in the 1990s and 2000s (e.g. energy-efficient light bulbs, electric cars, wind turbines).
- system transition, which includes a wider range of actors and entails radical visions of new kinds of systems and functionalities.

3.2.3 Geographical and temporal focus

Most socio-technical studies focus on the national sectoral level. Historical studies suggest that transitions may take 30-50 years. Studies of sustainability transitions often analyse developments from the recent past (e.g. 10-15 years ago) to the present. Some studies also focus on transitions in cities or on local projects, which often have a shorter term focus (5-10 years). There are some, but not many, studies that look far into the future. The reason for this is that many transition studies use case study methodologies, which describe and explain developments that have actually happened.

3.2.4 Typical methods and data

Many socio-technical transition studies use case study methodologies, because these enable investigations of topics in real-life contexts, focusing on causal links in complex situations in which many variables interact (Yin, 1994). Case studies are therefore often used, since socio-technical transitions are relatively rare and multi-dimensional processes. While transitions may have similarities in terms of basic elements and mechanisms, the way these combine in concrete transitions is likely to differ between countries (depending on actors, contexts and outcomes of specific struggles). Case studies are also able to address two specificities of transitions: longitudinal processes and co-evolution.

Case studies allow the analysis of non-linear processes over time (called 'process tracing'), which accommodates real-world dynamics such as setbacks, accelerations, unintended consequences, surprises, struggles, changing coalitions, shocks and surprises. Thus, case studies are not just stories but actually represent a conceptual view on how complex processes like transitions happen in the real world: 'Narrative explanation takes the form of an unfolding, open-ended story fraught with conjunctures and contingency, where what happens, an action, in fact happens because of its order and position in the story. Narrative therefore permits a form of sequential causation that allows for twisting, varied, and heterogeneous time paths to a particular outcome' (Griffin, 1993).

Case studies also enable the study of co-evolutionary alignments and lateral interactions between 'domains', as Tosh (2002) explains: 'Specialist expertise ...

compartmentalizes human experience into boxes marked "economics", "social policy" and so on, each with its own technical lore, whereas what is really required is openness to the way in which human experience constantly breaks out of these categories. These lateral links with different aspects of society are much easier to discern with the benefit of hindsight.'

Sewell (2005) further emphasises that big processes are always over-determined and have multiple causes, which need to be studied in interaction: 'One significant characteristic of historical events is that they always combine social processes with very different temporalities — relatively gradual or long-run social trends, more volatile swings of public opinion, punctual accidental happenings, medium-run political strategies, sudden individual decisions, oscillating economic or climate rhythms — which are brought together in specific ways, at specific places and times, in a particular sequence.'

Alongside the socio-technical field's focus on case studies, a recent research strand aims to use computer modelling techniques to investigate transitions (Holtz et al., 2015; Li et al., 2015), sometimes in combination with qualitative socio-technical studies (McDowall, 2014; Trutnevyte et al., 2014). These models make simplified, stylised and formalised representations of transitions, which are claimed to offer several benefits (Holtz et al., 2015):

- formalised assumptions are explicit, clear and systematic;
- mathematical models make it possible to calculate, infer or derive the dynamics that result from multiple interacting processes;
- models facilitate *ex ante*, systematic experiments via simulations.

Models can be used for various purposes, e.g. sharpening general understanding of transitions, offering case-specific policy advice, or providing platforms that facilitate stakeholder processes. While this is a promising research strand, there is an ongoing debate about the challenges that large-scale socio-technical processes pose for computer modelling. McDowall and Geels (2016) identify 10 challenges, including the following: hidden assumptions remain (also in formal models); uncertainty analysis frequently downplays deeper uncertainties; validation may be impossible for predictive model applications; models may close down certain questions in stakeholder processes; some characteristics of transitions are difficult to model (e.g. cultural meanings, interpretations, identities, institutions, conflicts and power struggles); and models gain generality at the expense of context specificity and real-world specificities.

3.3 Understanding and conceptualising transitions

3.3.1 Basic concepts and overall transition dynamics

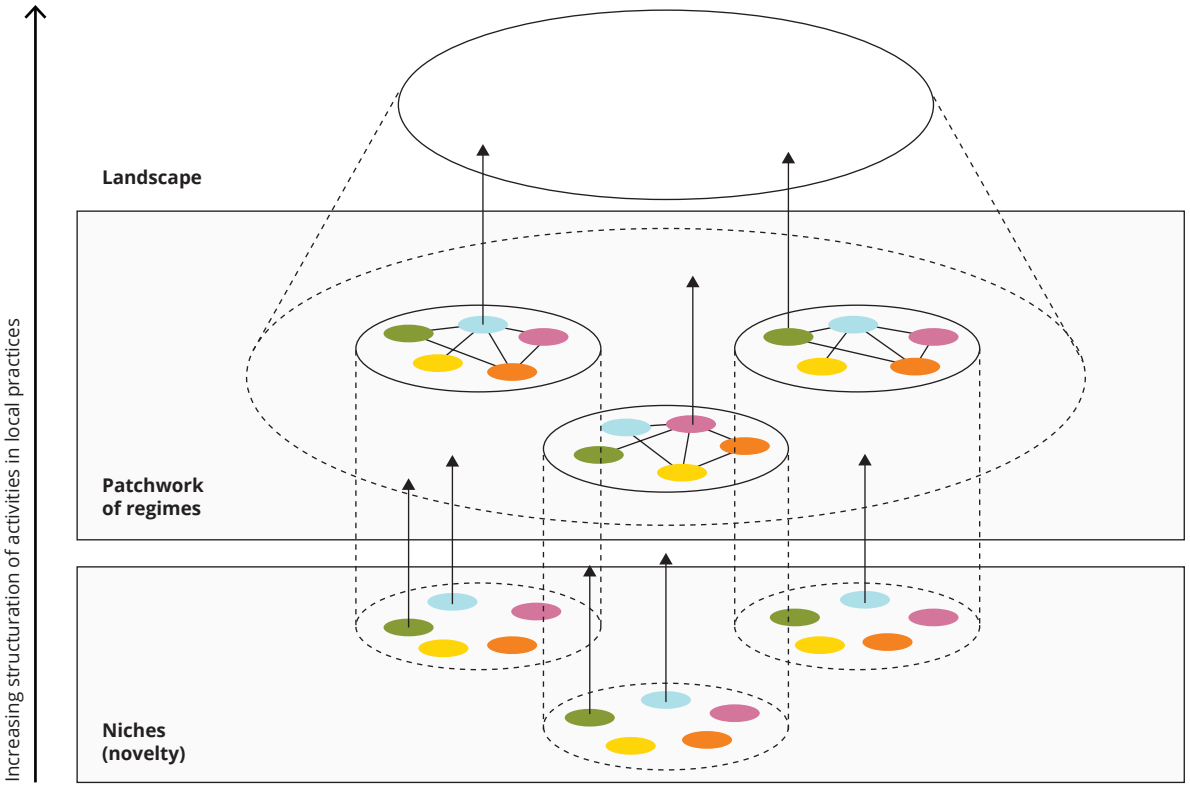
The multi-level perspective (MLP) has become the dominant way of understanding socio-technical transitions (Smith et al., 2010; Markard et al., 2012), combining ideas from evolutionary economics, sociology of technology and institutional theory. The MLP's basic premise is that transitions are non-linear processes that result from the interplay of multiple developments at three analytical levels: niches (the locus of radical innovations), socio-technical regimes (the locus of established practices and associated rules), and an exogenous socio-technical landscape (Rip and Kemp, 1998; Geels, 2002b, 2005b). These 'levels' refer to heterogeneous configurations of increasing stability, which can be seen as a nested hierarchy (Figure 3.5). The MLP helps to explain why there may simultaneously be a flurry of change activities (at the niche level) and relative stability of existing regimes. The three analytical levels are briefly described below.

Niches and the emergence of radical innovations

Radical novelties are conceptualised as emerging in niches, which are 'protected spaces' such as research and development laboratories, subsidised demonstration projects, or small market niches in which users have special demands and are willing to support emerging innovations (e.g. the military). Niche actors (such as inventors, start-up companies, outside firms) work on radical innovations that deviate from existing regimes. Mokyr (1990) characterised radical innovations as 'hopeful monstrosities': they are 'monstrous' because early inventions have relatively poor performance and high costs. But they are 'hopeful', because they offer some kind of valued functionality, which is why special kinds of users may be willing to invest in their further development.

Niche actors hope that their promising novelties are eventually used in the regime or even replace it. This is not easy, however, because the existing regime is stabilised by many lock-in mechanisms (described below). So, innovations may remain 'stuck' in niches for a long period of time, unable to cross the 'valley of death'. Previous research suggests that the period

Figure 3.5 Multiple levels as a nested hierarchy



Source: Geels, 2002b.

between invention (emergence of radically new ideas) and innovation (viable market introduction of products) is often about two or three decades.

Socio-technical regime and 'barriers to change'

Niche innovations often struggle against well-entrenched socio-technical systems, based on alignments of existing technologies, regulations, user patterns, infrastructures and cultural discourses (Geels, 2004). The system elements are reproduced, maintained and incrementally improved by incumbent actors, such as firms, engineers, users, policymakers, special interest groups and civil society actors. The perceptions and actions of these social groups are shaped by socio-technical regimes, which are shared rules, practices and institutions (e.g. technical knowledge paradigms, habits of use, prevailing normality, cultural discourses, established practices of professionals).

In existing regimes, innovation is mostly incremental because of lock-in mechanisms and path dependence. Change still occurs, but it proceeds relatively predictably in certain directions, giving rise to stable trajectories (Dosi, 1982). Based on different literatures various important lock-in mechanisms can be distinguished (Geels, 2004):

- Economic lock-in mechanisms include sunk investments (in competence, factories, infrastructure) that create vested interests against change and better price/performance characteristics of existing technologies, which benefit from economies of scale and decades of learning-by-doing improvements.
- Social lock-in mechanisms include cognitive routines and shared mindsets that 'blind' actors to developments outside their focus (Nelson and Winter, 1982); 'social capital' resulting from alignments between social groups; and user practices and lifestyles, which stabilise particular technologies (e.g. the car has become embedded in mobility practices such as commuting to work, taking children to school, shopping and social visits).
- Political lock-in mechanisms include active opposition to change from groups with vested

interests (Geels, 2014), which use corporate political strategies to shape policies in their favour (Hillman and Hitt, 1999; Levy and Egan, 2003), and existing regulations and policy networks that favour incumbents and create an uneven playing field (Walker, 2000).

External, contextual developments in a socio-technical landscape

The socio-technical 'landscape' is the wider context that shapes transitions in socio-technical systems. Rip and Kemp (1998) coined the landscape metaphor to emphasise material aspects such as physical geography, climate, urban layouts, roads, pipes and cables that form the taken-for-granted backdrop of daily life. Van Driel and Schot (2005) further elaborated the metaphor, distinguishing between slow-changing aspects (e.g. demographics, political ideologies and macroeconomic trends) and external shocks (e.g. war, oil price fluctuation, recession, accidents such as Fukushima or terrorist attacks).

This varied set of factors can be combined in a single 'landscape' category, because they form an external context that actors cannot influence in the short term. This context forms 'gradients' for action from which it is hard to deviate. This does not mean that landscape developments occur without human agency. Urbanisation, globalisation, environmental problems and macro-cultural changes obviously come about through the aggregation of multitudes of actions. The point, however, is that such landscape developments cannot be influenced by niche and regime actors in specific socio-technical systems.

Transitions resulting from multi-level interactions and alignments

The key point of the MLP is that transitions come about through the interplay between processes at different levels (Figure 3.6). Although each transition is unique, the general dynamic is that transitions come about through the interaction between processes at different levels: niche innovations build up internal momentum; changes at the landscape level create pressure on the regime; destabilisation of the regime creates windows of opportunity for niche innovations.

An important implication is that the MLP does away with simple causality in transitions. There is no single 'cause' or 'driver'. Instead, there are processes on multiple dimensions and at different levels that link up and reinforce each other ('circular causality').

3.3.2 Phases, actors and struggles in transitions

The complexity of transitions can be stylised by distinguishing different phases in transitions, characterised by different actors and core struggles. Figure 3.6 suggests that four phases can be distinguished.

Emergence

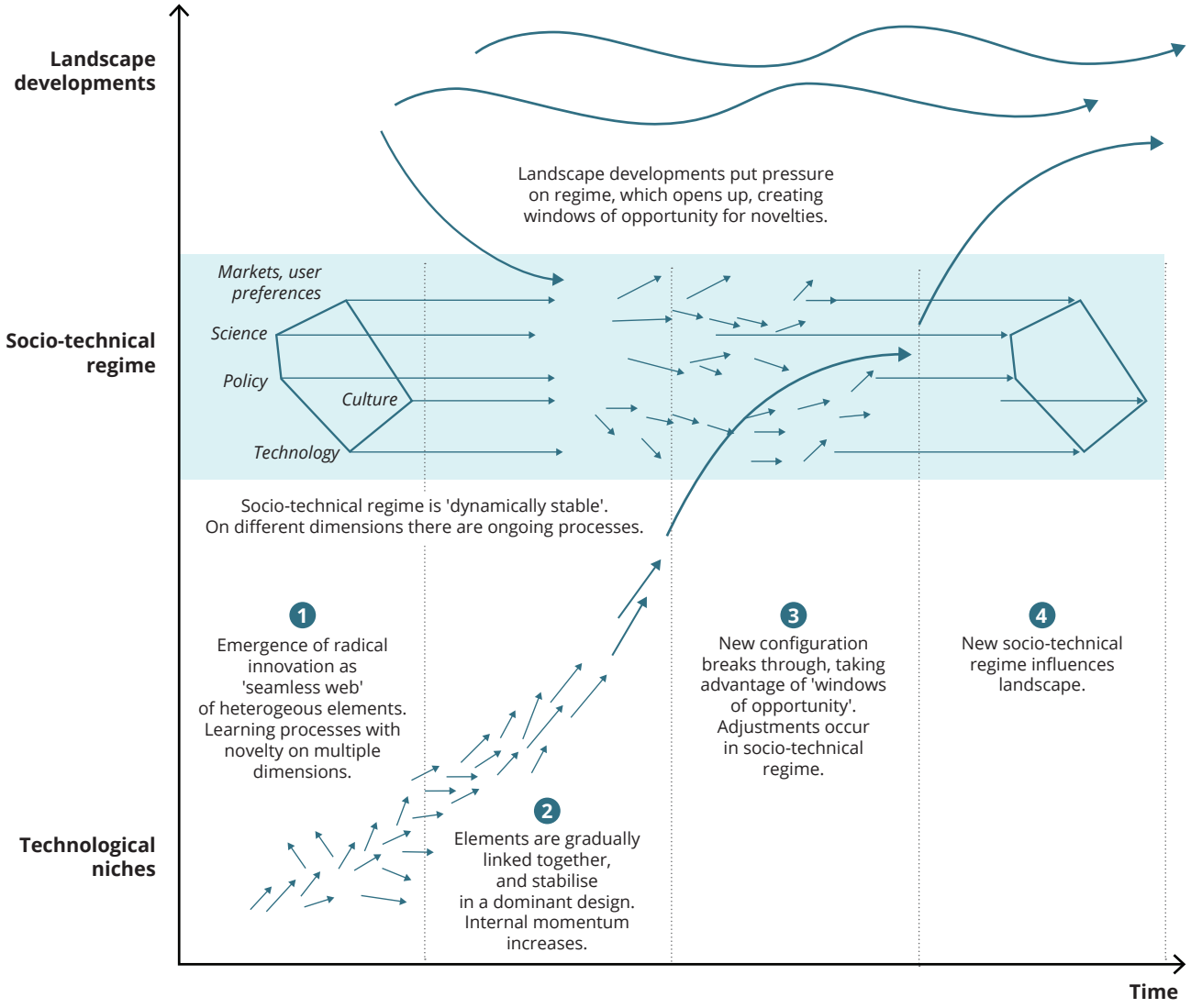
In the first phase of transitions, radical innovations emerge in niches, often outside or on the fringe of the existing regime. The social network of niche innovators is unstable and fragile with lots of entry and exit. There are no stable rules in this early phase. Various design options co-exist, linked to different social networks with diverging views and visions. There is much uncertainty about technological characteristics, user preferences, policy, infrastructure requirements and cultural meaning. The first phase is therefore characterised by experimentation and trial-and-error learning: 'Experimentation and learning precede up-scaling and widespread diffusion' (Wilson and Grübler, 2011).

The fluidity and divergence of niche innovations is represented by small diverging arrows in the bottom-left corner of Figure 3.6. Markets may not readily exist for radical innovations. There may be much uncertainty about who the consumers are, their preferences and the crucial functionality of the new technology. '[T]he prediction of how a given invention will fit into the social system, the uses to which it will be put, and the alterations it will generate, are all extraordinarily difficult intellectual exercises' (Rosenberg, 1972).

Radical innovations are risky and many pioneers and new entrants ultimately fail because of a lack of financial and organisational means (Olleros, 1986). The first phase 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).

In the first phase, niche innovations do not (yet) form a threat to the existing regime, which is entrenched in many ways (institutionally, organisationally, economically, culturally). Incremental changes in regime technologies, policy, markets and cultural meanings continue along relatively predictable trajectories (represented as stable lines in Figure 3.6).

Figure 3.6 Multi-level perspective on socio-technical transitions



Source: Geels, 2006.

Two specific frameworks to understand the dynamics in the emergence (and formative) phase are strategic niche management (SNM) and the TIS approach. These are briefly discussed below.

Strategic niche management

The SNM approach (Kemp et al., 1998; Geels and Raven, 2006) suggests that local, on-the-ground projects are important for the emergence of a broader (or 'global') field or community. These local projects are shaped by broader networks and visions, but also create outcomes that can inform broader community developments. SNM scholars distinguish three interacting processes (Figure 3.7) that enable the emergence of niche innovations:

1. Learning processes, e.g. technical learning that improves performance, and learning about markets and consumer preferences; infrastructure requirements; business models; cultural articulation of symbolic meanings; and the effectiveness of specific policy instruments. The results of learning processes are codified in various rules (e.g. design principles, standards, shared meanings, formal regulations and norms).

2. The articulation (and adjustment) of expectations or visions, which provide direction to the innovation

activities and attract attention and funding from external actors.

3. Building of social networks and enrolment of more actors, which expand the social and resource base of niche innovations.

Niche innovations gain momentum if visions become more precise and more broadly accepted, if the alignment of various learning processes results in stable rules and configurations, and if social networks become bigger. The participation of powerful actors in particular may add legitimacy and bring more resources into niches.

Technological innovation systems

The TIS approach (Hekkert et al., 2007; Bergek et al., 2008), which draws on insights from industrial economics and innovation systems, also conceptualises the emergence of radical innovations as a social process. Compared with SNM, it places more emphasis on entrepreneurs, resources and knowledge, as is visible in the seven functions that need to be fulfilled in effective innovation systems (Hekkert et al., 2007). These functions are:

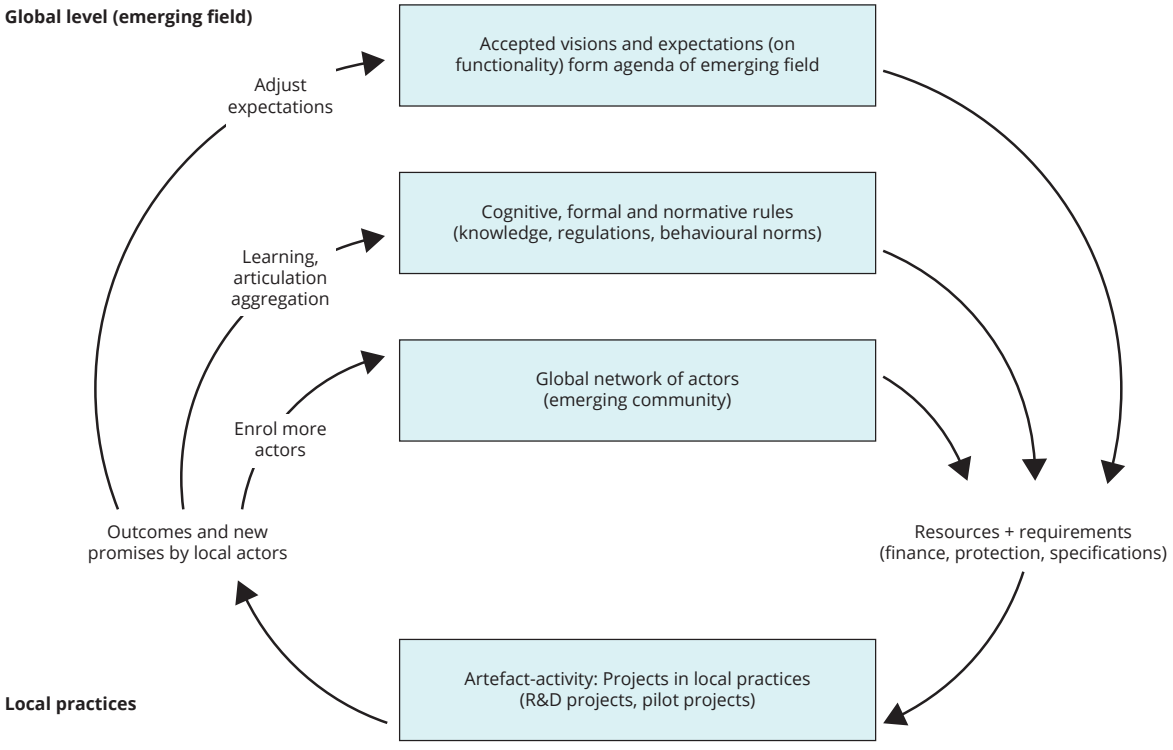
1. Entrepreneurial activities: Entrepreneurs drive innovation systems, exploiting business opportunities and performing commercial or practice-oriented experiments.

2. Knowledge development: Technological research and development (R&D) drives the content of innovation processes. Non-technological knowledge is also important.

3. Knowledge diffusion: Knowledge needs to be diffused throughout the whole network of actors, requiring information exchange between universities, research institutes, firms, policymakers and standard-setting bodies.

4. Guidance of the search: Knowledge generation is not blind but guided by expectations, visions, targets and goals, which can be influenced by policymakers.

Figure 3.7 The dynamics of niche development trajectories



Source: Geels and Raven, 2006.

5. Market formation: New technologies cannot immediately compete in mainstream markets. The creation of (niche) markets therefore helps to nurture innovations in early phases.

6. Resource mobilisation: Financial, material and human factors are necessary inputs for all innovation system developments.

7. Support from advocacy coalitions: The emergence of a new technology often leads to resistance from established actors. Innovation actors therefore often need to raise a political lobby that counteracts this inertia and supports the new technology.

Both the SNM and TIS approaches have been used in a wide range of empirical studies, leading to various refinements and nuances. Reflecting on these studies, SNM scholars moderated some of their initial claims: 'For one thing, we were certainly over-optimistic about the potential of SNM as a tool for transition. ... The positive circles of feedback by which a technology comes into its own and escapes a technological niche are far weaker than expected and appear to take longer than expected (5 years or more). ... The contributions of single projects to niche development appears to be small. ... The experiments were relatively isolated events. ... There are limits to the power of experiments. Only occasionally will an experiment be such a big success that it will influence strategic decisions. Experiments may tip the balance of decision-making, as has happened in many cases, but they will not change the world in a direct, visible way' (Hoogma et al., 2002).

Formative phase and stabilisation

In the second phase of transitions, innovations break out of protected technological niches and establish a foothold in one or more market niches. This provides a more reliable flow of resources, which stabilises the innovation, making it more attractive for new entrants. Learning processes gradually stabilise into a dominant design, which becomes institutionalised in design guidelines, product specifications and best-practice formulations carried by a dedicated community of firms, engineers, policymakers and users. The innovation thus develops a trajectory of its own because of the stabilisation of rules and social networks (represented in Figure 3.6 by converging arrows in the second phase).

Learning processes in this phase tend to focus on functionality and performance rather than cost: 'Performance dominates cost in initial market niches' (Wilson and Grübler, 2011). Cost-benefit calculations may be difficult to apply in this phase because of pervasive uncertainties about future technical performance, consumer demand and prices. In fact, over-reliance on financial assessment tools may act as 'innovation killers' in this phase (Christensen et al., 2008).

In this phase, new professions emerge that codify the new body of knowledge and transfer it to students through new curricula at teaching institutions. Dedicated professional groups will further improve the innovation and lobby for more policy support. Technological stabilisation and emerging economic opportunities increase the willingness of actors (government, firms, financial community) to invest. Innovation may also happen on the user side, as consumers '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 legitimise innovations and attract further support. 'Transitions are more likely to be considered successful when they contribute to a different vision of the "good life" (Wilkinson et al., 2012). Innovations may, however, also be opposed by social groups that experience negative side-effects or by citizens who feel insufficiently consulted in decision-making. Such opposition may result in controversy and stalemate, which hinders further progression of the innovation, as happened in some countries with nuclear energy, genetically modified food and onshore wind turbines.

Innovations may remain stuck in market niches for a long time, especially when they face a mismatch with the existing regime. As long as the regime remains stable, niche innovations often have little chance to diffuse more widely. Niche innovations and actors can follow two different patterns and strategies (Smith and Raven, 2012):

1. A fit-and-conform pattern, in which niche innovations try to compete on existing dimensions with the incumbent regime (e.g. existing markets, consumer preferences, policies, business models, cultural meanings).

2. A stretch-and-transform pattern, in which niche actors attempt to change regime structures to make them more favourable for niche innovations. This may entail various forms of entrepreneurship, e.g. political lobbying to change policies, economic entrepreneurship to open up new markets around new functionalities, cultural entrepreneurship to develop new discourses and storylines. Incumbent regime actors may actively resist these changes, leading to various kinds of fighting back and struggles (Geels, 2014).

Wide diffusion and breakthrough

In the third phase of transitions, the innovation diffuses into mainstream markets where it competes head on with the existing technology and wider socio-technical regime. The diffusion process is best seen as a pattern of 'niche-accumulation' (Geels, 2002b), with an innovation emerging in a technological niche, moving to a small market niche and subsequently to larger mainstream markets (Figure 3.8).

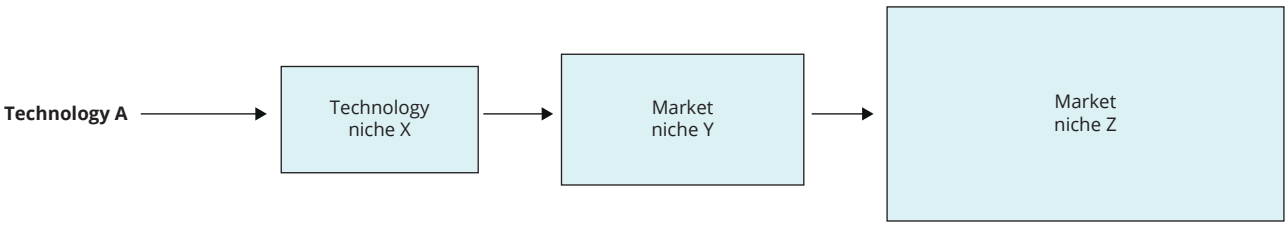
Broad diffusion typically depends on multi-level alignments. On the one hand, diffusion depends on niche-internal drivers such as virtuous cycles of processes within niches (Figure 3.7), price/performance improvements, scale economies, development of complementary technologies and support from powerful actors. On the other hand, diffusion depends on external landscape developments that put pressure on the regime, leading to tensions and an 'opening up' of the regime (represented by diverging arrows in Figure 3.6). Windows of opportunity may arise for the niche innovations because of:

- performance problems that cannot be met with the available technology;
- changes in markets and user preferences;
- changing cultural discourses that delegitimise existing technologies;
- changes in policy agendas that lead to stricter regulations;
- competition and strategic games that may lead incumbent firms to diversify away from existing technologies and towards niche innovations.

The third phase is often characterised by head-on struggles between niche innovations and existing regimes on multiple socio-technical dimensions:

- Economically, there is market competition between new and existing technologies, whose outcome depends not only on price/performance characteristics, but also on economic frame conditions and the institutions that shape and constitute markets.
- On the business dimension, there are struggles between new entrants and incumbents. These struggles may follow different patterns: first, the victory of new entrants may lead to the downfall of existing firms (Christensen, 1997); second, incumbent firms may successfully defend themselves by buying up the new firms, hindering the new innovations (through pricing strategies or political tactics) or improving their own technology; third, existing firms may diversify and reorient themselves towards new technologies. Car manufacturers, for instance, are currently diversifying towards hybrid and battery-electric vehicles. Electric utilities (in some countries) are also diversifying towards renewables. This means that incumbent actors can play constructive roles in transitions, even when they initially tend to resist.
- Political conflicts and power struggles about the precise settings of policy instruments (e.g. adjustments in the size and strength of subsidies, taxes and regulations) and the kinds of instruments (e.g. market-based, regulatory, informational) are likely. Political struggles also centre on which problems appear on agendas, how they are framed, and what degree of urgency is attached to them (Kern, 2011). These struggles involve both traditional policy actors (bureaucrats, ministers, advisory committees, political parties, parliament) and also many interest groups, which often have differential degrees of access to policy networks. Successful transitions are deeply political processes, because they usually require major changes in policy instruments and in market

Figure 3.8 Diffusion as a process of niche-accumulation



Source: Levinthal, 1998.

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, e.g. strengthening of change coalitions and weakening of incumbent networks.

- Transitions are also about cultural and discursive struggles, which frame problems and solutions in certain ways (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 tax) or as a 'planetary boundary' (which may lead to stronger regulations 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 low-carbon energy producers or existential threats? Different social groups may have different views and interpretations, which may lead to social opposition or enthusiasm. These cultural dimensions are important with regard to social acceptance of solutions and the legitimacy of policy efforts. 'Whatever can be done through the state will depend upon generating widespread political support from citizens within the context of democratic rights and freedoms' (Giddens, 2009).

There is no guarantee that niche innovations will win these struggles. They may fail to build up sufficient momentum or suffer setbacks. Tensions in existing regimes may remain small so that 'windows of opportunity' for niche innovations do not (sufficiently) materialise. Or incumbent actors may successfully counter-mobilise and thwart or stall niche innovations.

Stabilisation, institutionalisation and addressing unintended consequences

The fourth phase of transitions is characterised by technological substitution and broader socio-technical adjustments in user practices, infrastructures, regulations and cultural meanings. These changes become anchored in rules and institutions such as regulatory programmes and new agencies, habits of use, views of normality, mindsets, professional standards and technical capabilities. Shifts to new socio-technical systems may also create unintended consequences that need to be monitored and, if necessary, adjusted. Potential 'losers' in transitions may need to be helped or compensated to limit potential resistance.

3.3.3 Processual characteristics of transitions

The MLP considers transitions fundamentally as alignments of multiple processes, which are seen as event chains, based on actions and interactions between a variety of social groups. More specifically, and based on the various theories that inform the MLP, these processes have the following characteristics:

- They are evolutionary, which means that they are open ended, non-linear, fundamentally uncertain and based on searching, learning, trial and error, and experimentation. Transitions are also disruptive and characterised by punctuated equilibria (Gersick, 1991), meaning that long periods of relative stability are punctuated by brief periods of disruption and overthrow. In biological evolution, this involves the extinction of species; in socio-technical transitions this may involve the downfall of existing firms and industries (Schumpeter, 1939).

- They are contested, conflictual and deeply political, involving a range of struggles, as indicated above. The reason is that transitions entail various social groups with different interests. These groups will advocate or oppose changes that advance or hinder their interests. Policy change, which is an inevitable dimension of transitions, is an obvious dimension of conflict. But conflict also occurs in economic and cultural dimensions. Because of these struggles, transitions may have stop-start dynamics, for instance, when fighting back leads to weakening of policies: 'Transitions are not teleological and deterministic, but continuously enacted by and contested between a variety of actors. … So, transitions are likely to be non-linear; two steps forward may be followed by one step back (or steps in a different direction if actors change their beliefs and goals or if there is growing contestation of particular pathways)' (Geels et al., 2016d).

- They are about meanings, interpretations, beliefs, mindsets and sense-making. These cultural and interpretive dimensions are important because they shape the motivations and preferences of actors and the definition of interests. They also influence the social acceptance and cultural legitimacy of transitions. This does not necessarily mean that transitions will be consensual, as different groups may have different beliefs and interpretations. But it does mean that transitions should not be seen as only techno-economic management challenges, as some governments and policy advisors do. Transitions are also about societal debates and the development of appealing visions that inspire people to act.

- Transitions are likely to involve surprises and unintended outcomes as changes in complex systems are non-linear and often have unforeseen knock-on effects. This means that actors should find a balance between commitment and determination (which are important to create drive and momentum), on the one hand, and flexibility to change course or address side-effects, on the other.

3.4 Empirical examples

There are many empirical studies of green niche technologies such as wind turbines, solar photovoltaic (PV) panels, biogas, electric vehicles, fuel cell vehicles, biofuels and low-energy housing. There are also many niche studies of social and organisational innovations such as car sharing, community energy and battery-leasing (e.g. Better Place). These studies apply the MLP, SNM, TIS, TM, discourse theory or political science theories to investigate particular aspects or causal mechanisms. Most of these innovations are still in early phases of development, so they have limited usefulness to illustrate entire transitions.

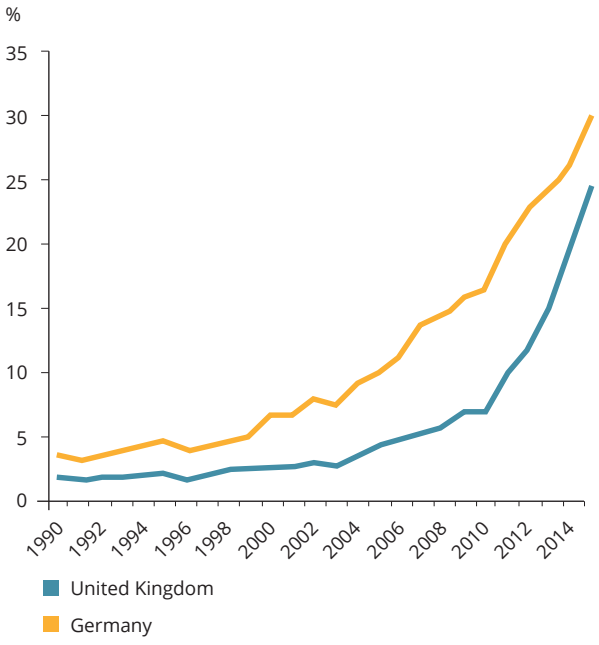
There are also dozens of studies of historical transitions that have demonstrated the usefulness of the MLP. But these studies are less relevant to contemporary sustainability problems, which have certain specificities. First, private actors have limited incentives to address sustainability transitions because sustainability is a collective good, which implies free-rider problems; this implies that public authorities and civil society are crucial to internalise negative externalities. Second, many green niche innovations have lower price/performance characteristics than existing systems, so they require prolonged policy support.

Against this background, a comparative study of electricity transition in Germany and the United Kingdom is chosen to briefly illustrate various aspects of MLP (see Geels et al., 2016, for an extensive study). Although not completed, the transition towards renewable electricity has substantially progressed in both large European countries, reaching 30.1 % in Germany and 24.7 % in the United Kingdom in 2015 (Figure 3.9). A drawback of this example is a focus on the supply side and electricity generation. An advantage is that the case shows that transitions are possible and already under way in some domains. It also shows that countries may follow different pathways to achieve similar goals.

Niche innovations

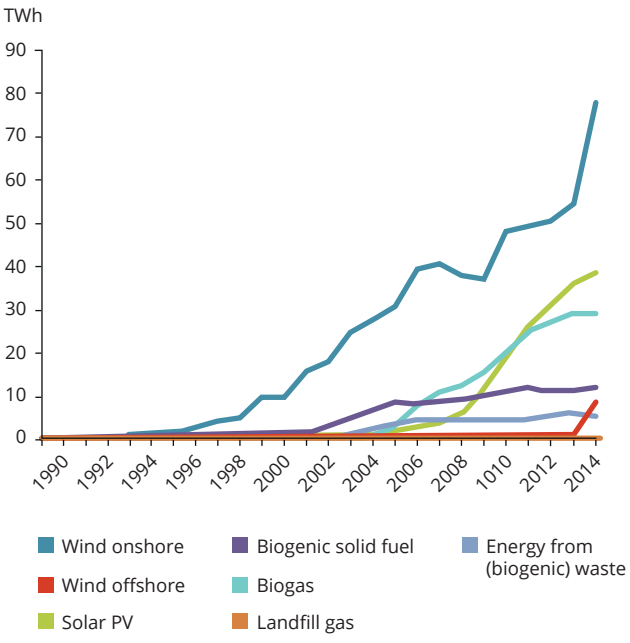
In terms of technologies used, there are major differences between the two countries. Germany mainly

Figure 3.9 **Renewable electricity as a percentage of total electricity generated in the United Kingdom and Germany, 1990-2015**



Source: DUKES, 2016; AGEB, 2016.

Figure 3.10 **Power production from German renewable energy technologies, excluding hydroelectric power 1990-2015**



Source: AGEB, 2016.

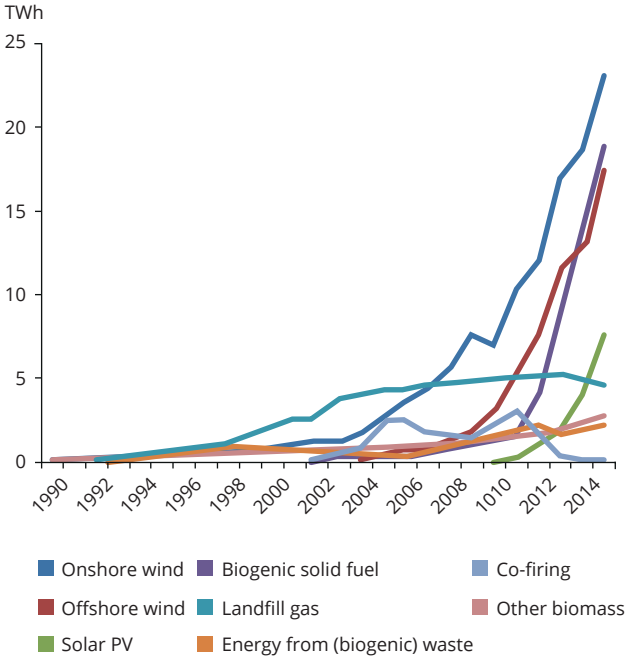
deployed small-scale decentralised renewable energy technologies (RETs), such as onshore wind, solar-PV and biogas (Figure 3.10), while the United Kingdom mainly deployed large-scale centralised RETs such as onshore wind farms, offshore wind farms, biomass conversion of coal power stations and use of landfill gas (Figure 3.11) ([1]). The United Kingdom also considers two other large-scale low-carbon options — nuclear power and carbon capture and sequestration — to be key to its electricity transition. These options are not seen as part of the German low-carbon transition.

Niche actors

Another major difference relates to the kinds of actors deploying RETs. In Germany, most RETs were deployed by new entrants into the sector, such as households, farmers, municipal utilities and banks (Table 3.1). In 2010, the 'Big 4' utilities suppliers (RWE, E.ON, Vattenfall, EnBW) accounted for only 6.5 % of the total renewable electricity generated.

In the United Kingdom, on the other hand, most RETs were deployed by large corporate actors such as utilities, project developers, landfill site operators and waste companies. Since the introduction of a feed-in-tariff in 2010, there has been some growth in community energy wind and solar-PV, but these continue to face uphill struggles because of 'the persistence of key features of socio-technical regime

Figure 3.11 Power production from different UK renewable energy technologies, excluding hydroelectric power, 1990-2015



Note: 'Other biomass' includes biogas, sewage sludge and animal biomass.

Source: DUKES, 2016.

Table 3.1 German ownership structure of installed capacity of different renewable electricity technologies in 2010 (%)

	Households	Farmers	Banks, funds	Project developers	Municipal utilities	Industry	Four major utilities	Others
Wind	51.5	1.8	15.5	21.3	3.4	2.3	2.1	2.2
Biogas	0.1	71.5	6.2	13.1	3.1	0.1	0.1	5.7
Biomass	2.0	0.0	3.0	6.9	24.3	41.5	9.6	12.7
Solar-PV	39.3	21.2	8.1	8.3	2.6	19.2	0.2	1.1

Source: Geels et al., 2016d.

([1]) Onshore wind can be implemented as large-scale wind farms (many dozens of turbines operated by project developers or utilities) or in smaller numbers (1-15 turbines operated by citizens, farmers or cooperatives). The former option is more prevalent in the United Kingdom and the latter in Germany, where 68 % of wind parks are smaller than 10 MW (data from *Bundesnetzagentur*).

for electricity provision, which continues to favour large corporations and major facilities' (Strachan et al., 2015). Because of these differences, Geels et al. (2016d) characterise the German pattern as 'unleashing new entrants' and the UK pattern as 'working with incumbents'. The latter means that niche innovations are not always developed by new entrants, as suggested in Section 3.1, but can also be developed by incumbent regime actors if they diversify and reorient (part of) their strategies towards niche innovations.

Niche support policies

The countries also differed in terms of policies. In Germany, technology support programmes (R&D, demonstration projects) created early technological niches in the 1980s, enabling farmers, environmentally motivated citizen groups and smaller utilities to deploy small wind turbines. These were complemented by the 1990 feed-in-law, which created protected market niches, because it obliged utilities to buy renewable electricity at a guaranteed price. It also excluded big utilities from participation. Market support was further extended with the 2000 Renewable Energy Sources Act (EEG), which guaranteed a minimum payment for 20 years and adjusted financial support levels to the maturity of different technologies. Although the EEG experienced various adjustments, it provided a stable and attractive investment environment. In 2011, the Fukushima nuclear accident, a major landscape shock, caused significant public uproar because of a pre-existing negative discourse and the active anti-nuclear movement. The subsequent nuclear phase-out decision, which immediately closed eight nuclear plants and planned to close the remainder by 2022, put pressure on the existing regime and created a window of opportunity for the further diffusion of RETs (Figure 3.12).

During the same period, the United Kingdom was characterised by more unstable policy instruments, which changed much more frequently: the Non-Fossil Fuels Obligation (1990-1998); the Renewables Obligation (2002-2009); the Amended Renewables Obligation (2009-2016); and the Contract-for-Difference (2016-2020). These instruments were mainly auction and trading instruments, which aimed to achieve the lowest costs. They also favoured incumbents (because of risks and administrative complications) and created barriers to new entrants, which helps explain the observed actor patterns noted above. Other policies such as a feed-in tariff (since 2010), the community energy strategy (since 2014) and the solar-PV strategy (since 2013) were added and remained less significant than the other policies.

Regime and landscape developments

In terms of regime dynamics, the UK coalition between utilities and the government has remained fairly strong throughout the whole period studied. This explains, first, why the UK renewables policy was formulated to suit the interests of utilities and, second, why the UK climate policy envisages a continued role for regime technologies such as nuclear power (the government intends to build eight new nuclear plants) and gas (the government promotes shale gas and new gas-fired power plants). For coal, the government (unsuccessfully) tried to get demonstration projects for CCS (carbon capture and sequestration) off the ground. The new UK government elected in 2015 abandoned this plan, but committed to phase-out unabated coal by 2025 if feasible alternatives are available by then, which looks uncertain because of major delays in the government's nuclear plans.

In Germany, the regime coalition between utilities and the government was disrupted by a landscape development: the election of a Red-Green government (1998-2005). That government made an initial nuclear phase-out decision, which was overturned in 2009 and reinstated in 2011, and implemented the EEG support policy. Incumbent utilities were also affected by the economic recession (another landscape shock), increasing RET-competition and the 2011 nuclear phase-out decision. As a result of these pressures, net profits of the Big 4 declined (Figure 3.13) and share prices tumbled by 75 % from 2006. Because of concerns that the utilities might collapse, the government has substantially decreased EEG support since 2012 with the aim of moderating RET expansion.

Conflicts and struggles

Both transitions experienced conflicts and power struggles, which led to advances or setbacks. Some of the German struggles were the following:

- German utilities resisted the renewables support policies. They contested the legality of the 1995 Feed-In Law in German courts in 1995 and the European Court of Justice. They consistently tried to delegitimise renewable electricity, developing a negative discourse of RETs as expensive and unreliable. Since 2009, this discourse has gained increasing traction with the Conservative-led government coalitions. Combined with concerns over the economic viability of utilities, since 2012 the government has downscaled EEG support, with severe reductions in 2014 that also set upper limits for RET expansion.

- There were political struggles between ministries over the responsibility for renewable energy policy. In 2002, the Red-Green government transferred this responsibility to the Ministry for Environmental Affairs. In 2014, the government transferred the responsibility back to the Economics Ministry, which was less positively oriented towards RETs.

- There have been continuous struggles over nuclear policy. Utilities fought the 2002 phase-out decision, lobbied the Conservative-Social Democrat government (2005-2009) for a roll-back, succeeded in 2009, were faced with a U-turn in 2011, and have since sought financial compensation in court cases.

The UK transition also experienced struggles:

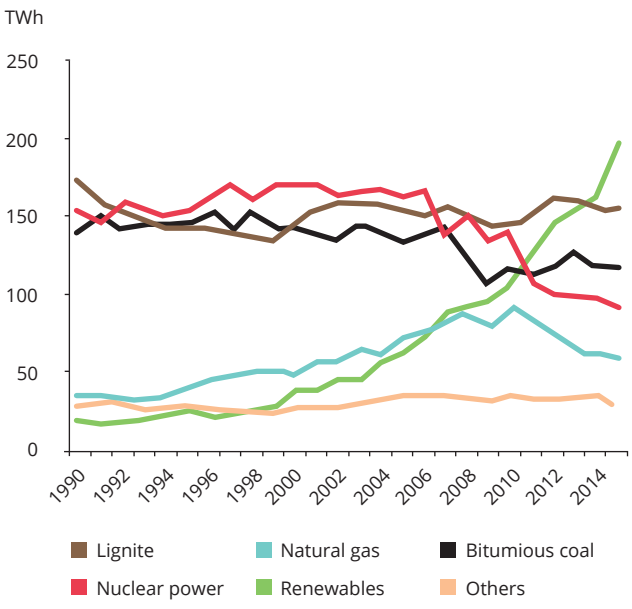
- New entrants contested renewable support policies, which worked against them. They had little success, however, as policymakers ignored and sidelined them.

- Nuclear policy reappeared on the policy agenda in 2005, supported by Prime Minister Blair. Greenpeace won a court case that stated that the government had insufficiently consulted with the public, as had been promised earlier. Prime Minister Blair then launched a consultation exercise, but said in advance that 'this won't affect policy at all' (BBC, 2007).

- Several innovations, which were supported by government and utilities, faced major implementation and social acceptance problems, because of lack of proper consultation. Onshore wind farms faced increasing local opposition because citizens felt that burdens (noise, visual burdens, shadow flicker) were insufficiently addressed. Subsequently, approval rates in planning procedures decreased from 73 % in 2007 to 50 % in 2012. There have also been strong local protests against plans for shale gas and fracking. The government went ahead anyway, with Prime Minister Cameron personally expressing strong commitment in a letter to *The Telegraph*, dismissing protesters as uninformed 'NIMBY' activists (The Telegraph, 2013). 'Big Biomass', in which old coal plants convert to burning biomass, also faced public protests because of sustainability concerns regarding imported pellets. These experiences led Geels et al. (2016d) to suggest that the UK government has a 'bulldozer' policy style that pushes through concocted plans rather than consulting with citizens and societal actors.

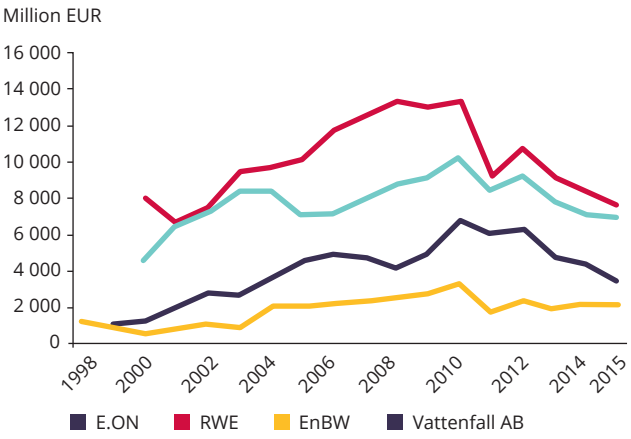
- There have been political struggles over the salience of climate change. This problem gained political momentum in the mid-2000s, because high-level politicians chose to compete on the issue, which resulted in the ambitious 2008 Climate Change Act. Since the financial-economic crisis, however, the political commitment has

Figure 3.12 German electricity generation by fuel type, 1990-2015



Source: AGEB, 2016.

Figure 3.13 Net profits of the 'Big 4' utilities



Source: Kungl and Geels, 2016.

weakened, as political attention shifted towards jobs, competitiveness and energy prices. The right wing of the Conservative party became more vocal, criticising subsidies for onshore wind and questioning climate change science. The Treasury started issuing warnings that green policies should not hinder the economy. In 2013, cost concerns escalated into a full-scale political row over rising energy bills, which led the Conservative-Liberal Democrat coalition government to scrap, delay or water down various green policies. In 2015, the new Conservative government further slashed support policies for onshore wind, solar-PV and biomass plants, because projects already in the pipeline were sufficient to reach the 2020 target of producing 30 % of electricity from renewable sources. There are no post-2020 renewables targets.

Non-linearities and surprises

The German transition experienced the following non-linearities and surprises:

- The solar-PV boom in the mid-2000s was not foreseen. Because solar-PV received more subsidy, the boom pushed up the EEG-surcharge, which enhanced the traction of utilities' complaints that RETs were expensive.
- The extra costs were initially legitimated with a 'green growth' discourse, because German solar manufacturers were a domestic and international success story. In the late 2000s, however, unforeseen competition from Chinese solar-PV manufacturers bankrupted several German firms and eroded this discourse.
- The 2011 Fukushima accident was an external shock that destabilised the German nuclear power regime.
- The expansion of intermittent renewables (solar-PV, wind) disrupted 'normal' market functioning leading sometimes to negative prices ([2]).
- The nuclear phase-out and subsequent *Energiewende* paradoxically increased carbon emissions because of increased use of lignite (Figure 3.12) to fill capacity gaps. This is likely to be a temporary effect.

The UK transition experienced the following surprises:

- The unforeseen US shale gas revolution changed UK energy policies, which intended to emulate it (despite different geological structures). The US shale gas revolution also led to greater US coal exports, which decreased the price leading to greater coal use in the United Kingdom (increased by 32 % in between 2011 and 2012).
- The political row over energy costs in 2013 was unforeseen, leading to reductions in various green policies.
- The government's commitment to offshore wind is surprising, as it is one of the most expensive RETs, which conflicts with the UK's normal focus on low costs.
- The rapid growth solar-PV since 2010 was unforeseen. The government tried to catch up by, belatedly, introducing a solar-PV strategy (2014).
- The development of CCS and nuclear power is much slower than intended, which could potentially create serious capacity problems in the mid-2020s (which might jeopardise the intended phase-out of unabated coal).
- The scrapping of 10 green policies by the new Conservative government was unforeseen, and has led to about 18 000 job losses in the solar installation sector.

These brief empirical examples demonstrate some of the processual characteristics described in Section 3.3, as well as the basic categories of the MLP. The examples illustrated not only some recurring patterns and struggles, but also that the specific mechanisms and conflicts vary substantially between countries, depending on actor coalitions, policy styles and national characteristics.

3.5 Governance of transitions

3.5.1 Governance and policy mix

Transitions are difficult to manage and steer, because they are open, uncertain and complex processes, involving multiple social groups and system elements, many of which are outside the immediate control of policymakers. The state is not an all-powerful and all-knowing actor, which can steer system innovation

([2]) This could happen on sunny, windy days when renewables produced more power than markets demanded, forcing utilities to switch off existing power plants. In 2013, there were 96 hours of negative prices, causing additional costs of EUR 90 million.

by pulling levers from an outside 'cockpit' point of view (Hajer et al., 2015). Rather, policymakers are dependent on firms (for knowledge, resources, innovation, jobs and taxes) and the wider public (for legitimacy and consent). Furthermore, policymakers are not one actor category, but fragmented across different sectors and levels (e.g. international, national, local).

In political science, this awareness has led to a shift in focus from 'government' to 'governance' (Rhodes, 1997; van Heffen et al., 2000). Governance means that there is directionality and coordination at the systems level, but that it has an emergent character, arising from the interaction between multiple societal groups. Public authorities have special responsibilities and resources to shape this emergent directionality, but they cannot steer it entirely at will.

The political science literature further usefully distinguishes three policy paradigms, which differ in their view on social relationships, roles of policymakers, coordination and preferred policy instruments (Table 3.2). Transitions cannot be brought about by a single policy instrument. Instead, the governance of transitions requires a mix of policy instruments (Kivimaa and Virkamäki, 2014). Market-based and regulatory instruments are well known, and often emphasised. For instance, the United Nations report *Towards a Green Economy* (UNEP, 2011b) suggests that 'there is a need for better public policies, including pricing and regulatory measures, to change the perverse market incentives that drive this capital mis-allocation. … To make the transition to a green economy, specific enabling conditions will be required. … At a national level, examples of such enabling conditions are: changes in fiscal policy; reform and reduction of environmentally harmful subsidies; employing new market-based instruments; targeting public investments to "green" key sectors; greening public procurement; and improving environmental rules and regulations as well as their enforcement.'

The Organisation for Economic Co-operation and Development (OECD) report (2011) *Towards Green Growth* also argues for changes in fiscal and regulatory settings (such as tax and competition policy), innovation policy and environmental policies that 'include a mix of price-based instruments (for instance environmentally-related taxes) and non-market instruments such as regulations, technology support policies and voluntary approaches'.

But Table 3.2 also includes an interactive network governance paradigm, which encompasses processual policy instruments that have particular salience for transitions. These instruments are typically under-represented in high-level policy advice from the OECD and the United Nations Environment Programme (UNEP).

3.5.2 Governance of sustainability transitions and 'transition management'

The evolutionary logic of the MLP suggests that policymakers should follow a two-pronged strategy to influence transitions:

Table 3.2 Different policy paradigms

	Market model (bottom-up)	Classic steering (top-down)	Interactive network governance
Characterisation of relationships	Autonomous (government creates incentives and 'rules of the game', but lets autonomous actors choose freely)	Hierarchical, command-and-control (government sets goals and or tells actors what to do)	Mutually dependent interactions
Characterisation of coordination processes	Incentives and price signals coordinate self-organising actors through markets	Government coordinates through regulation, goals and targets	Coordination happens through social interactions and exchange of information and resources
Foundational scientific disciplines	Neo-classical economy	Classic political science	Sociology, innovation studies and neo-institutional theory
Policy instruments	Financial incentives (subsidies, taxes)	Formal rules, regulations and laws	Demonstration projects and experiments, knowledge transfer policies, network management, vision building through scenario workshops, strategic conferences and public debates

Source: Based on de Bruijn et al., 1993.

1. enhance variation by stimulating the emergence and diffusion of niche innovations;

2. change the selection environment by enhancing pressure on regimes through economic instruments and regulation (e.g. taxes, carbon emission trading, environmental legislation).

The relative importance of both strategies, and the policy mix, is likely to vary over time. The first strategy (nurturing innovations) will be more important in the first two transition phases, because this helps generate alternatives and new advocacy coalitions. Policy instruments from the third paradigm in Table 3.2 (demonstration projects, scenario workshops, vision building exercise, public debates, public-private partnerships) have a large role to play, since they are well-suited to deal with uncertainty, learning, opening up new markets and building of new networks. General environmental policies, like the articulation of future goals and targets, also have a role to play as they indicate directionality and urgency. Furthermore, some instruments from the first and second paradigm in Table 3.2 may be relevant, e.g. financial subsidies for projects or exemptions from particular regulations if these hinder experimentation. Whereas exploratory innovation policy is appropriate in the first phase, attention should additionally be given to industrial policy in the second phase, particularly offering support for new firms and opening up new markets.

In the third and fourth transition phases, when there is more clarity about technology, market demand and infrastructure requirements, the second strategy gains importance. Policy instruments such as environmental regulations or pricing (carbon taxes, cap-and-trade, subsidies,) can be used to exert pressure on the existing regime and support the diffusion of niche innovations. Vested interests and incumbent actors may resist these policies, which is why their introduction requires support from the new industries and support coalitions that were nurtured in the early transition phases ([3]). It may also be useful to develop policies that assist 'losers' (e.g. retraining of staff, buy-outs, compensations, sunset clauses) to diminish potential resistance. Figure 5.1 schematically positions the varying policy mix in the MLP.

Further emphasising particular aspects of the above strategy, Weber and Rohracher (2012) distinguish four specific challenges for the governance of sustainability transitions:

1. Directionality: Sustainability transitions are purposive, i.e. oriented at solving social and environmental problems. The articulation of visions (e.g. via foresight exercises or societal debates) and political goals is therefore crucial.

2. Demand articulation: Demand for radical innovations is not waiting 'out there', but may need to be articulated; active market creation often co-evolves with new technologies through a 'probe and learn' process (Lynn et al., 1996).

3. Policy coordination: Transition policies need to be (horizontally) coordinated with sectoral policies (transport, energy, agro-food). High-level political support is also needed to enhance the visibility of transition initiatives in the early phases and the legitimacy of more selective policies in the third phase.

4. Reflexivity: Transitions are open-ended and uncertain processes. Evaluation and regular monitoring should enable timely adjustments and feedback into policy design.

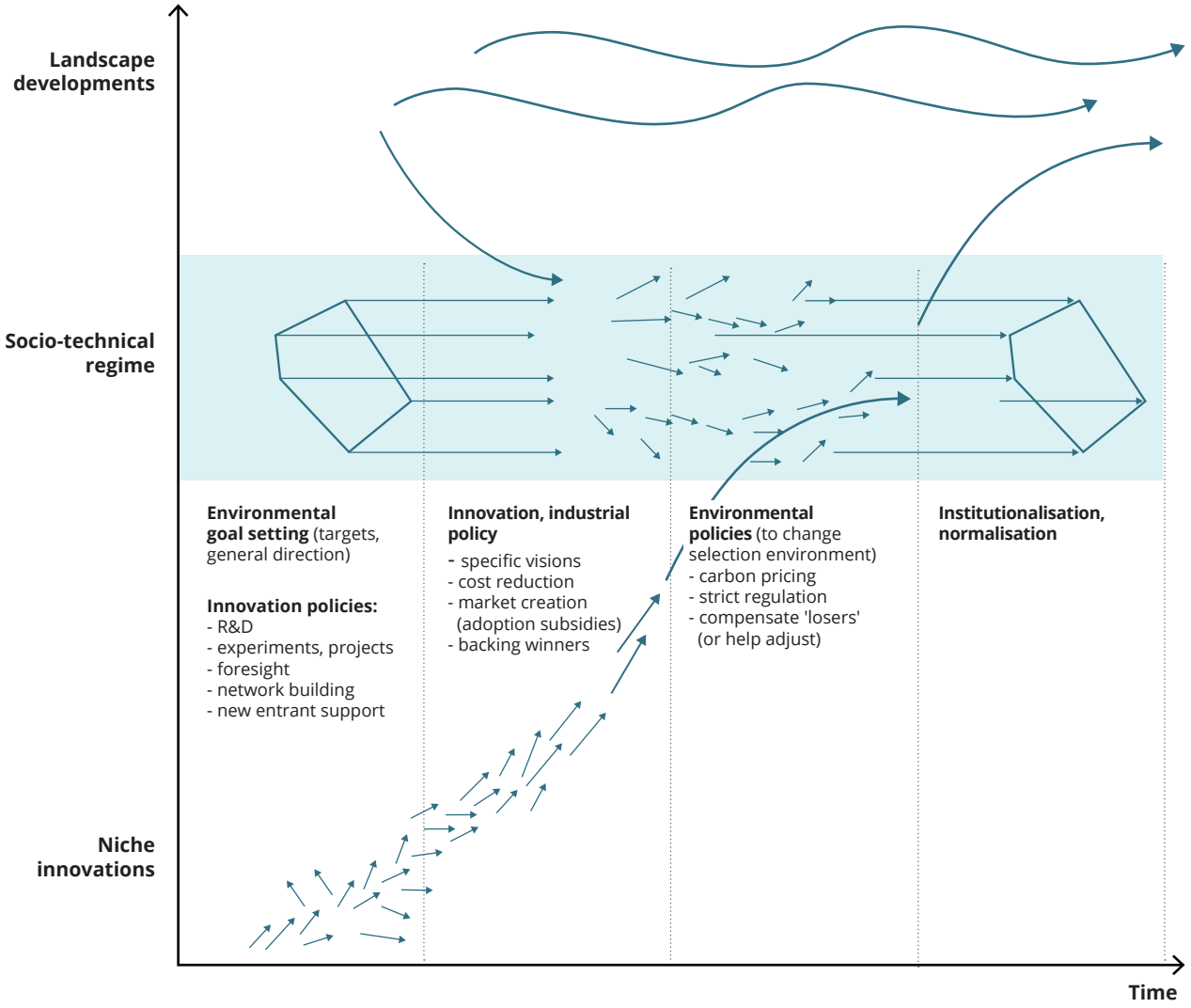
Transitions management

Transition management (TM) is a prescriptive approach that promises to address some of these challenges, although its actual implementation in the Dutch energy transition programme (2002-2010) had several shortcomings. TM advocates (Rotmans et al., 2001a; Kemp et al., 2007a; Loorbach, 2010) characterise the approach as 'goal-oriented modulation', in which long-term visions offer directionality for a variety of transition pathways that are explored with short-term projects that lead to learning outcomes that inform subsequent visions. TM thus claims to be forward looking and adaptive. Concretely, TM includes four sequential steps or activities (Loorbach, 2010):

1. Strategic activities aim at vision development, strategic discussions and the identification of potential transition pathways to reach the goals. These activities take place in a 'transition arena', which includes not only regime actors, but also 'frontrunners' (e.g. opinion leaders, entrepreneurs, NGOs, knowledge institutes) who think 'out of the box'.

([3]) This also means that it will be difficult to introduce tough policies (such as substantial carbon pricing) in the early phases, as support coalitions will be insufficiently developed to take on incumbent actors.

Figure 3.14 Shifting mix of policy instruments during socio-technical transitions



Source: Geels, 2006.

2. Tactical activities develop more specific plans for concrete routes and build agendas and support coalitions for these routes, preferably with investment commitments.

3. Operational activities include on-the-ground activities such as innovation experiments, demonstration projects and implementation activities, aimed at learning-by-doing. Transition pathways are thus explored by 'walking the talk'.

4. Reflexive activities include the evaluation of projects, assessment of agendas and monitoring of progress and directionality of the overall transition. Evaluation outcomes should lead to suggestions for adjustments in overall visions, specific policies or the articulation of best practices.

TM has been criticised on general grounds. Hendriks (2009), for instance, suggests that it lacks democratic accountability, since a small group of actors in 'transition arenas' articulate long-term strategic directions without much wider involvement. Shove and Walker (2007) suggest that TM pays insufficient attention to politics and downplays conflict through technocratic and consensual language. TM also pays insufficient attention to 'normal' policy instruments such as taxes, regulations and incentives, which can put pressure on regimes.

The concrete implementation of TM in the Dutch energy transition programme also deviated in several respects from the ideal-type prescriptions.

- First, regime actors (businesses, technology developers and energy specialists) were over-represented, and there was limited involvement of civil society, consumers or the wider public.

- Second, the energy transition programme remained an isolated endeavour with limited reflexivity or wider social embedding, as TM proponents themselves observed: 'Nevertheless, it is not the open, reflexive process it was supposed to be. ... It has not become politically salient in Parliament and society is not really involved in it' (Kemp et al., 2007a).

- Third, most actual innovation projects had a narrow technical focus with a focus on business creation, which neglected wider social, behavioural and systemic changes. 'The transition experiments are very technological by nature; they hardly aim at institutional or cultural change. They consist of rather low-risk projects primarily related to CO_2 reduction' (Kemp et al., 2007a). The energy transition programme thus became fairly technocratic and similar to regular innovation policy.

- Fourth, the bottom-up initiatives and projects were not complemented by policies that put pressure on the existing regime (which is a broader issue in TM): 'So far, the attention for transitions has not resulted in changes in fiscal policies or in environmental policies that will be needed to change the energy supply system' (Kemp et al., 2007a).

3.5.3 Varieties of capitalism, political economy and power struggles

Countries have different policy styles and are thus likely to manage transitions with different instrument mixes and different coalitions. Building on the varieties of capitalism literature (Coates, 2000; Hall and Soskice, 2001; Tiberghien, 2007), four styles can be distinguished with different relations between state and private sector:

1. Liberal market economies (e.g. Australia, Canada, United Kingdom, United States) — a liberal state limits its role to rule-setting and conflict settlement, leaving coordination to occur mainly via market competition.

2. Coordinated market economies (e.g. Austria, Denmark, Germany, Netherlands) — an enabling state arbitrates among economic actors and facilitates interactions via cooperative relationships.

3. State-influenced market economies (e.g. France, Japan, South Korea) — the state plays a more active and interventionist role in the economy.

4. State capitalism (e.g. Arab states, China, Russia) — the state or state-owned enterprises undertake commercial activities.

These different styles influence the kinds of policy instruments that countries are likely to use to shape transitions. Liberal market economies will generally prefer market-based instruments. Coordinated/corporatist economies are more likely to use network governance instruments (see Table 3.2). In state-influenced market economies and state capitalist countries, classic steering instruments may be more popular. Countries are also likely to differ in their view on the appropriate role of governments in system innovation.

Transitions are deeply political projects, because making and implementing major policy changes are difficult and contested processes. First, there is the normal problem of reluctance to change, related to institutional inertia and institutional path dependence (Pierson, 2000). Second, there will be active resistance and lobbying from powerful incumbent actors, whose vested interests may be threatened. Corporate interests have much influence on the policy process and may be able to hinder institutional change or create loopholes, as Levy and Newell (2000) note: 'The European Commission undertakes business roundtables on a regular basis to consult with leading industrialists. The European Roundtable of Industrialists, made up of chief executive officers from 45 leading European companies, is arguably the most influential interest group in Brussels. ... Although environmental groups may exercise influence in setting the agenda, when the point of decision is reached, large multinational companies and the organisations that represent them have key access to members of the Commission, ministers, and heads of government in Member States.'

Particularly in the third phase, when niche innovations compete with existing regimes in mainstream markets, incumbent players are likely to flex their economic and political muscles to protect their interests. The literature on corporate political strategy (Yoffie, 1988; Hillman and Hitt, 1999; Scherer et al., 2009) suggests that firms can use a range of strategies to shape policy-making processes.

- Information and framing strategy. Industries can: (1) set up research institutes or sponsor favourable research; (2) use this expertise to contest scientific

findings and draw attention to uncertainties; (3) report research results to influence policy debates or demonstrate the (in)feasibility of certain solutions; or (4) testify as expert witnesses in policy hearings.

- Financial incentives strategy. To influence policymakers, industries can: (1) make contributions to politicians or political parties; (2) pay fees for speaking at conferences; or (3) offer politicians lucrative jobs at the end of their career.

- Organised pressure strategy. Industries can mobilise networks to create pressure through: (1) mobilisation of employees, suppliers, customers, etc., who send letters and pressure their representatives; (2) creating fake grassroots organisations ('astroturf') that claim to speak on behalf of public interests, but are funded and managed by industries; or (3) create industry associations that speak for the industry.

- Direct lobbying strategy. Industries can: (1) hire lobbyists; or (2) directly mobilise company executives to engage governments.

- Confrontational strategies. Industries can: (1) oppose laws through litigation; (2) threaten policymakers with plant closures, layoffs or relocation; (3) refuse to implement policies; or (4) comply only partially with policies.

3.6 Strengths and weaknesses

The MLP's understanding of transitions has several strengths (Turnheim et al., 2015).

- Its focus on socio-technical systems offers a middle way between two dichotomous approaches in the environmental social sciences focused either on macro-contexts (the nature of capitalism, modernity, society) or on individuals (choices, attitudes, motivations). Because of its attention to dynamics at multiple analytical levels, the MLP offers an integrative view on transitions, ranging from local projects to niches to sector-level regimes and broader societal contexts.

- The focus on concrete socio-technical systems and associated actors enables a nuanced analysis of the multiple social groups involved and the various kinds of agency (Geels, 2010), including searching, learning, sense-making, strategic investments, power struggles, conflict, coalition building and goal-setting.

- The MLP pays attention to agency and events, but also to broader structures, institutions and 'rules of the game' (including shared cognitions and norms). It thus navigates a middle way between voluntarism (the idea that actors can freely shape the future they want) and determinism (which precludes creativity and choice).

- Empirical case studies with the MLP enable understanding of the real-world complexities of transitions (including setbacks, struggles, surprises and uncertainties), while not drowning in the micro-details of singular studies of local projects.

- The MLP pays attention to stability (via analyses of path dependence and the inertia of existing regimes) and change (via analyses of niche development processes and change initiatives). This offers a remedy against the ideological bias of sustainability scholars who focus only on positive 'green' developments.

- The MLP is multi-dimensional, aiming to understand the co-evolution of technology, markets, consumer practices, politics, culture, business, science and the environment. Unlike mainstream academic disciplines, which tend to focus on single dimensions, the MLP is not reductionist.

- The MLP offers policy advice in the form of general strategies, indicating what kinds of struggles are likely in which phases and what kinds of policy instruments may be most suitable. It also highlights uncertainties and the political feasibility of particular policies (depending on advocacy coalitions and windows of opportunity). Its steering philosophy is based on 'modulating on-going processes' rather than on control and management. This philosophy requires an understanding of transition processes, which is what the MLP provides.

The MLP also has weaknesses and under-developed areas:

- The empirical focus has, so far, mostly been on sectors and systems with clearly identifiable technological components (e.g. electricity, transport, heat and buildings). Agro-food and water management systems can also be studied with a socio-technical approach, although this has been done to a lesser degree. The socio-technical focus remains different, however, from a socio-ecological one, which suggests potential complementarities.

- Its conceptual understanding is mainly 'appreciative' and qualitative, supported largely by case studies.

Formalisation and quantitative analysis are less developed, although there is an emerging research stream on transition models (Holtz et al., 2015; Li et al., 2015), discussed above.

- The MLP does not generalise in terms of laws, final causes or ultimate drivers, which are uniform across contexts. Instead, the MLP generalises by identifying recurring causal mechanisms that combine in various ways in specific cases to generate context-specific patterns.

- Although the socio-technical approach emphasises actors and struggles, the MLP has been criticised (mainly by science and technology studies scholars), however, for insufficiently addressing the role of agency in transitions. Smith et al. (2005), for instance, portray the MLP as 'dominated by rational action' and 'too descriptive and structural, leaving room for greater analysis of agency'. Genus and Coles (2008) state that the MLP 'undervalues the role of agency and politics' and ask for more 'concern for actors and alternative representations that could otherwise remain silent'. Shove and Walker (2007) criticise the MLP for focusing too much on supply side actors and making 'almost no reference to the ways of living or to the patterns of demand'.

- The MLP focuses more on processes than on sustainability impacts of transitions. Therefore, it does not really indicate to what degree environmental problems will be alleviated if certain 'green' innovations lead to system change.

- Most empirical studies of 'green' transitions focus on dynamics in the recent past and present. The MLP is used in a limited way for long-term forward-looking analyses, although there are some attempts to develop socio-technical scenarios.

- Policy advice is rarely prescriptive and instrumental (indicating what the precise settings of policy instruments should be to achieve certain goals).

3.7 Knowledge for socio-technical transitions

3.7.1 The need for new competencies and awareness of transitions thinking

Socio-technical transitions theory and the MLP are relatively new and have not yet become widely institutionally embedded. As such, its instrumental effect on policy has been limited. However, various agencies (Tekes, Vinnova, Flemish Environment Agency), policy think tanks (OECD, German Advisory Council on Global Change), NGOs (Forum for the Future) and national Ministries (Netherlands, United Kingdom) have become interested in the MLP as a tool for providing a strategic framework for policy-thinking.

The MLP is not a 'truth machine', whereby one enters the data, churns the handle and collects the answers. Instead, it is a heuristic analytical framework that requires empirical knowledge of specific sectors to enable strategic 'big picture' sense-making. Its use by policymakers is therefore likely to require new competencies and strategic intelligence. This probably also requires interaction between policymakers and academics to enable 'co-production' and mutual learning and adjustments.

Effective governance of transitions may require policymakers to develop new roles and policy styles (to address uncertainties and enable broad stakeholder engagement). It may also require moves away from neo-liberal and generic innovation policy, which focus too much on framework conditions (taxes, subsidies, environmental rules and regulations, intellectual property rights) and inputs (public investments, public procurement), and too little on supporting social networks, demonstration projects, learning processes, vision exercises and societal debates (Table 3.2).

Transitions should not be approached solely as a techno-economic planning challenge, building only on knowledge from engineers, modellers and economists. Transitions should also be seen as deeply political projects (requiring high-level 'political will'), as societal projects (including interactions with stakeholders and citizens to achieve support) and as cultural undertakings (requiring positive visions and discourses that create legitimacy and enthusiasm). Also the open-ended, uncertain and non-linear character of transitions should be acknowledged, with sufficient attention given to disagreements between groups about the pros and cons of different transition pathways. This points to the need for policymakers to acquire more reflexive knowledge and awareness of the general characteristics of socio-technical transitions, as described in Section 3.3.

3.7.2 Empirical knowledge to support transitions

A variety of different types of research will be needed to get inside the 'black box' of sustainability transition and provide the knowledge to support governance processes.

First, empirical knowledge is needed about how socio-technical transitions are actually unfolding in specific sectors, countries and political economies. There is unlikely to be one single answer or policy strategy. Instead, effective 'modulation of on-going dynamics' requires real-world understanding of these dynamics in specific sectors and countries, which should lead to different policy mixes and strategies.

Second, to assess the internal momentum (and possible 'barriers') of niche innovations, knowledge, data and evidence on the following dimensions would be helpful.

- Techno-economic developments: price/performance data on innovation, amounts of investments and market shares.

- Socio-cognitive: the coherence of visions with regard to particular innovations and degree of agreement about future directionality, the size of social networks and support coalitions, and the possibility of support from powerful actors.

- Governance: the political feasibility and effectiveness of policy instruments for particular innovations; the strength of support coalitions for policy reform.

Third, it is also useful to assess the stability of existing regimes, since this shapes the likelihood of resistance or reorientation of incumbent actors.

- To assess the degree of lock-in and stability, information would be needed on the commitment of firms and policymakers to existing systems and technologies and on the size of sunk investments.

- To assess the degree of tension and cracks in existing regimes, information would be needed on the degree of user dissatisfaction, the degree of technical bottlenecks and limits to incremental improvement and on dissatisfaction within closed industry fronts (if some firms are willing to defect, this may make it easier for policymakers to bring about change).

Based on this kind of processual information, policymakers can decide to focus their strategies on nurturing niche innovations, accelerating their diffusion, or increasing the selection pressure on incumbent regimes.

3.7.3 Methodologies for combining analytical perspectives

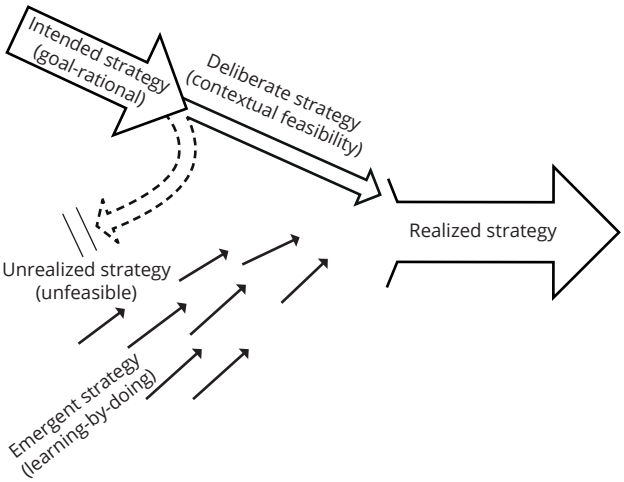
The socio-technical understanding of transitions and the MLP are not sufficient to govern transitions. An important research challenge is how the MLP can be combined with other analytical approaches such as traditional tools (modelling, cost-benefit analysis) and on-the-ground action research of local projects, to support more comprehensive governance strategies. Full integration of different approaches is not possible because of fundamental differences in ontological assumptions and methods (Geels et al., 2016a). But a potentially promising strategy is 'bridging', based on dialogue and interaction of independent approaches (McDowall, 2014a; Turnheim et al., 2015). Using a suite of interacting approaches may enable governance strategies that accommodate multiple policy-relevant criteria (indicated in bold below).

- Computer models and economic cost-benefit analyses may be used to offer goal-oriented analyses of the cost-efficiency of 'green' options and their **effectiveness** in reaching environmental goals. These approaches, however, are often based on stylised assumptions with a techno-economic orientation.

- Socio-technical transitions theory may be useful in assessing the socio-political feasibility and social acceptance of green niche innovations by analysing the interpretations, strategies and resources of different social groups. Regime analysis of stability and tensions may also identify potential windows of opportunity for these niche innovations and degrees of resistance ('barriers').
- Detailed action research of local projects may be useful to assess on-the-ground experiences with specific 'green' solutions and concerns of specific stakeholders. Such analyses may not only inform policymakers about the social acceptance of particular transition pathways, but also identify novel 'bottom-up' solutions, which introduce flexibility and creativity into the policy process.

This multi-approach strategy aligns with the synthesis of Mintzberg et al. (1998), who found that strategies in complex situations arise from combinations between 'intended', 'deliberate' and 'emergent' approaches (Figure 3.15). Such strategies allow decision-makers to combine goal-rational, contextual and experimental rationalities, which are arguably more suited for open-ended, non-linear and contested processes like socio-technical transitions.

Figure 3.15 Realised strategies arising from combinations between intended, deliberate and emergent strategies



Source: Mintzberg et al., 1998.

4 Socio-economic transformations: insights for sustainability

René Kemp, Paul M Weaver, Tim Strasser and Julia Backhaus (Maastricht University) and Ami Golland (University College London)

4.1 Introduction

This chapter discusses scholarly contributions to socio-economic transformations, with special attention given to lessons for sustainability policy. It reflects on how insights can be instrumentalised to achieve sustainability goals and the limitations of certain strategies and instruments, for example eco-efficiency policies.

The topic of socio-economic transformation addresses the economy in its different forms (profit-based, benefit-based and hybrid forms) and variants (varieties of capitalism and sectoral differences). It further addresses human needs, especially immaterial needs; personal use of time; and relationships between behaviour and context. In the socio-economic perspective, humans are seen as social and moral beings, who operate in socio-economic settings that shape their behaviour, identities, beliefs and interests. The focus is on the link between the economy and society, with a special focus on the role of capitalism, the money economy and markets in shaping consumers, consumption decisions, work activities and government policies.

Whereas the socio-technical literature emphasises the technologies of production, the socio-economic literature is concerned more with the level and structure of consumption and with materialistic and consumerist lifestyles. It is concerned with market institutions that shape and frame markets and with the political economy of the growth paradigm and its globalisation. Attention is given to the 'cultures' that institutionalise and drive individuals, organisations and societies to high levels of material consumption, as well as to cultural change and the motivations and practices of counter-movements.

Transformations have been described by Reißig (2014) as a 'transfiguration of the type of social and cultural order and development'. Transformations are said to be complex, multidimensional processes 'evoked by endogenous causes, sources, impulses, events: economic, social conflicts, crises, and tension lines'. They are associated with the 'establishment of new core actors as carriers of the new developmental mode, the institutionalisation of substantially different, alternative and future-proof rules and structures' (Reißig, 2014). Something that is transformed can never go back to exactly what it was before.

This chapter identifies two transformations: first, the transformation of society into a market society; second, a much weaker transformation of the economy-society-nature relationship into a more humane, 're-embedded' rather than dis-embedding, relationship, wherein the quality of human relations and environmental well-being are more fundamental than the maximisation of private profits. These transformation processes are not the only ones that exist. From the point of view of sustainable development and well-being, however, they are the most important socio-economic transformations because they are about work and living. Both processes are intermingled with globalisation, reform of the welfare state, acceleration of the pace of life and modernity becoming 'liquid', in the sense that social relations (in work and forms of living) are less permanent (Bauman, 2003) in various ways.

While technological change has an essential role to play in enabling societies to reconcile high living standards with environmental sustainability, focusing only on production technologies has major limitations due, in part, to the rebound effect. Technological progress that reduces production costs can lower product prices, facilitate market growth and support further economies of scale. This self-reinforcing cycle of cost reduction and market expansion — the 'Salter cycle' — is an engine for economic growth, but it undermines supply-side environmental policy focused on technologies that use resources more efficiently (Weaver, 2008). As a result, technology-induced resource efficiency gains are being more than offset by global growth in production and consumption.

A resource-switching transition on the supply side (e.g. to renewable energy) could represent a longer

term technological transition strategy, promoted by short- and mid-range policies seeking resource efficiency improvements. However, these would need to be supported by institutional changes to prevent the gains being lost to rebound effects and the emergence of perverse outcomes, such as eco-efficiency policies inadvertently further locking in the use of traditional resources and existing process or product solutions.

In practice, policymakers are limited in their policy options by conflicts between the goals of economic growth and full employment, on the one hand, and environmental protection, on the other hand. In an attempt to reconcile economic growth with environmental protection, governments have tended to focus on the transition to 'green growth'. But well-being can also be found in less materialistic ways with the help of the sharing economy, the mutual aid economy and the use of alternative currencies to give people a chance to build local economic resilience. This can create opportunities outside the mainstream economy, which is increasingly unreliable as a source of work and income, and enable people to move towards different lifestyle and consumption models. Accepting this may free up the lock-in that besets government policymaking.

The socio-economic transformation literature helps in understanding why governments struggle to pursue environmental policy forcefully and the need for institutional change and reform in the money economy and human activities. It brings out the complexities of environmental management in a capitalistic society, but also shows entrance points for action. Above all, the literature shows the need for systemic change, not only in socio-technical systems, but also in the system of capitalism and the process of marketisation, which has been the dominant force of transformation in the last two centuries, together with emancipation and democratisation.

Problems of environmental degradation, inequality and uprooting in capitalist societies show that a different notion of welfare is needed, based on a good life and catering for immaterial needs, which are currently undervalued and undermined. Environmental protection will benefit from attention being given to a more human form of capitalism and from cultural change away from consumerism and towards quality of life. Working less and creating a complementary economy runs counter to the policy goal of getting people into paid jobs, which is the overriding concern of governments in a debt-stricken world in which material wealth is achieved at high social and environmental costs.

4.2 Conceptual background and assumptions

4.2.1 A mixture of disciplines and analytical approaches

Socio-economic transformation is not a single field of study, but a topic studied by people in different disciplines. Analysis of socio-economic transformation draws on the following disciplines ([4]):

- Political economy — for example, Polanyi's work on the role of market ideologies, philosophies and institutions leading to the commodification of labour, land and money, with the resulting exploitation of nature and humans (Polanyi, 1944).
- (Historical) sociology — for example, the work of Tilly (1992) on changes in social relations during the industrial revolution, and Freeman and Louca (2001) on the interdependence and co-evolution of social, economic and technological systems. Another example is Schor's work on the socio-economic drivers of undesirable patterns of behaviour, including consumerism and work (Schor, 2001, 2010).
- Political philosophy — addressing liberalism, emancipation and Sandel's negative assessment of a market society (Sandel, 2012).
- (Positive) psychology — for example, Kasser's work on the harms associated with materialism, and the psychological factors driving unhealthy lifestyles (Kasser, 2003).
- Environmental and ecological economics — providing a conceptual toolkit to explain unsustainable activities in terms of issues, such as externalities, property rights and collective action problems. Quantitative economic analysis and accounting provide the basis for designing policy responses.
- Institutional economics —providing insights into the way that socio-economic institutions order human interactions (Lewis and Steinmo, 2012; Streeck and Thelen, 2005).

([4]) This report includes insights from science and technology studies and welfare economics, but these are seen as less foundational to the analysis of socio-economic transformations.

- Nature-society relations — a branch of geography connecting human with physical geography and studying the social construction of nature as well as the intertwinement of people's lives with physical resources.

Methods and data

Reasoned history (Freeman and Louçã, 2001) based on qualitative events, practices and developments, is the main method underpinning analyses of past transformations. Such analysis seeks to explore and explain the dynamics of observed transformation processes and highlight the systemic differences between pre-existing and new situations. It also explores topics such as the significance of transformations in terms of possibilities opened or closed; social, economic and environmental impacts; and the relevance for power, policy and governance. In addition to contributing to substantive knowledge, such studies contribute to the development of transition concepts, theory and methods for socio-economic analysis, which increases the usefulness of the methods for prescriptive applications.

Prescriptive transition approaches ascribe a positive role to visioning, experimentation and the use of policy mixes, with policy coordination and evaluation as transversal elements (Rotmans et al., 2001b; Kemp et al., 2007b; Loorbach, 2007). The clarification of visions and long-term goals serves the important purpose of giving direction to investors, innovators and consumers, while experiments help to generate lessons for practice. Omniscience on the part of the government is not required: 'what is needed is a set of mechanisms that recognizes errors and revises policies accordingly' (Rodrik, 2014). Policy choices are made 'along the way' on the basis of proposals from transition councils, regional collaborative innovation centres and learning experiences at different levels. The transition management approach acknowledges that a successful phase-in of green technologies requires a long time span with several cycles of adjusting policies (Kemp and Never, 2017). Systems analysis and integrated sustainability assessment (Weaver and Rotmans, 2006) are relevant supports to prescriptive transition approaches.

4.2.2 The influence of markets, institutions and policy

Calls for fundamental transformation in socio-economic systems reflect a recognition that the co-evolution of social and economic systems has resulted in patterns of individual and collective behaviour that are environmentally unsustainable and harmful to human well-being in important respects.

Culture and values

The cultural element of high levels of consumption is examined by American sociologist Juliet Schor in various publications. While she accepts the basic economic assumption that people generally favour more consumption over less consumption, she says that we are locked into a 'cycle of work and spend'. The mechanisms behind this are consumption competition, labour market rigidities preventing people from working fewer hours, and ecological resources not being properly priced (Schor, 2001). Consumption competition today is said to go beyond 'keeping up with the Joneses': the new dominant goals are acquisition of status goods and luxury (Schor, 2001). The reference groups for consumer aspirations have become less horizontal and more vertical, with people aspiring to achieve wealth that allows them to buy boats and aeroplanes.

According to Schor, the decline of community and sociability, especially at the neighbourhood level, and the growing importance of media, especially television, are important drivers behind consumption competition. Instead of consumption making us happier, it leads people to live excessively busy and stressful lives. In the words of Tim Jackson (2005a), 'people are being persuaded to spend money that they don't have, on things they don't need, to create impressions that won't last, on people they don't care about'.

Tim Kasser offers evidence that materialism is making people unhappy, not happy. He argues that 'people who are highly focused on materialistic values have lower personal well-being and psychological health than those who believe that materialistic values are relatively unimportant'. He also finds that materialism is linked to insecurity: 'when needs for security, safety and sustenance are not satisfied, people place a strong focus on materialistic values and desires'. According to Kasser (2003), people are trapped in materialism: 'people believe in materialism because society is so materialistic, and society is so materialistic because many people believe that materialistic pursuits are a path to happiness'.

Institutions and market/policy failure

Much work is organised around the idea that many dominant institutions — inherited from earlier times when environmental issues were a lesser

concern — introduce systematic bias or distort incentives and information systems in favour of overconsumption of environmental goods and services. Similarly, inherited information systems overlook, or fail to adequately measure or account for, environmental overconsumption.

Institutions can be identified at different levels of aggregation, without there being a strict hierarchy: 'the idea of institutions as "regimes" evokes the insight that institutions are multi-layered, that they sometimes overlap, that they can be ambiguous, and that they contain contradictory logics' (Lewis and Steinmo, 2012). For example, Kern and Howlett (2009) argue that employing transition management to achieve an energy transition in the Netherlands in an 'already complex energy policy mix' made 'the alignment of different policy goals and instruments very difficult'. They further note that 'achieving consistency, coherence and congruence should not be seen as an easy managerial task but one which will involve "tough" political struggles about the relative importance of different policy goals as well as the design and implementation of suitable instruments to achieve them'.

Policy regime analysts (as distinct from policy analysts) offer additional insights into why and how policy lock-ins can occur. Policy regime analysts recognise at least four dimensions of a policy regime: power arrangements, policy paradigm, organisation of government and state institutions, and policy instruments. Policy analysts tend to focus on the last of these (instrument choices), while overlooking the three other dimensions (Wilson, 2000).

According to Swilling et al. (2015), power arrangements (dimension 1) refer to 'how power relations are arranged and reproduced within the regime, that is, how political power is constituted, distributed and maintained by those who have power, especially — but by no means exclusively — the governing party and its allies within and outside government'. The underlying policy paradigm (dimension 2) is about 'the way policy problems are understood by the different policy actors who engage in the everyday business of politics (who usually share the same underlying paradigm — for example neo-liberalism — but differ on what policy option to adopt)'. The way government and state institutions are organised and operated (dimension 3), reflects the power relations and paradigm commitment, but they are not entirely determined by these power relations. The last dimension (dimension 4) concerns 'the policies that are debated and adopted by policy actors within a given socio-political regime'.

Often, policy analysts fail to consider dimensions 1 and 2 as shaping factors for the use of policy instruments. As Swilling et al. (2015) write: 'the advantage of policy regime theory is that it goes beyond the usual superficial level of policy analysis, which is primarily at dimension four and to some extent at dimension three. However, the evidence suggests that policies reflect underlying power dynamics (dimension 1) and paradigm commitments (dimension 2), and therefore unless these are changed, change in the other dimensions is unlikely.'

The disappointing results with the Emission Trading System for carbon emissions in Europe illustrate these concerns (Vatn, 2015). In allocating emission rights, national governments and the European Commission were under pressure from energy-intensive industries to provide those rights for free. The Commission gave in to those pressures out of fears of job losses and carbon leakage (Egenhofer, 2013).

The question of how to address climate change mitigation also highlights important methodological challenges for policymakers and their economic advisors: to what extent should challenges like climate change mitigation be addressed using orthodox economic methods? Moreover, in the event that orthodox methods are used (e.g. cost-benefit analysis), what is the appropriate discount rate? High discount rates work against strong forms of environmental protection.

Comparable concerns have also been raised over the behavioural assumptions of orthodox economic models. Assumptions about rational behaviour can restrict the capacity of models to project futures based on expectations and anticipatory behaviour of economic agents, leaving policymakers with a set of policy options limited to maintaining the status quo. Orthodox models and methodological assumptions can contribute to lock-in by not representing the dynamic interplay inherent between policymakers and economic agents in any transition.

Dominant systems and indicators for measuring economic performance and social progress also raise concerns. For example, in its analysis of the biases and omissions of mainstream indicators and accounts, the Commission on the Measurement of Economic Performance and Social Progress (CMEPSP) commented that 'it has long been clear that GDP is an inadequate metric to gauge well-being over time particularly in its economic, environmental, and social dimensions, some aspects of which are often referred to as sustainability' (CMEPSP, 2009).

The CMPESP report is about measurement rather than policies. However, there is a strong, transitions logic to the approach and to the recommendations of its authors. The logic is that changes in the design and use of progress measures are important for enabling and supporting sustainability transitions. For example, the Commission recommended that evaluations of well-being should look at income and consumption rather than production; emphasise the household perspective; consider income and consumption jointly with wealth; give more prominence to the distribution of income, consumption and wealth; and broaden income measures to include non-market activities.

The Commission also concluded that well-being, as a multi-dimensional concept, encompasses material living standards (income, consumption and wealth); health; education; personal activities including work; political voice and governance; social connections and relationships; environment (present and future conditions); and insecurity, of an economic as well as a physical nature. All these dimensions shape people's well-being, but many are missed by conventional income measures.

The Commission recommended restricting economic valuation and focusing monetary aggregation only on items for which reasonable valuation techniques exist, such as physical capital, human capital and certain natural resources. In the Commission's view, separate sets of physical indicators will be needed to monitor the state of the environment, particularly in relation to irreversible or discontinuous alterations to the environment.

From the perspective of sustainability transitions, one of the most important insights and recommendations of the Commission arises from its analysis of the components of well-being. Effectively, it is a call for a needed rebalancing in the attention paid to material and immaterial wants, and for a greater recognition of human needs relating to freedom of choice and autonomy. The Commission recommended taking steps to improve measures of people's health, education, personal activities and environmental conditions. An important consideration is the extent of people's opportunity set and of their freedom to choose among this set, i.e. the capacity to choose the life they value. In the Commission's view, people's use of time is a potentially useful indicator of quality of life. For example, comparing the proportion of time during which the strongest feelings are negative versus positive.

4.2.3 Socio-economic transformation as changes in systems and paradigms

Political lock-ins and the role of social innovation

Neoliberal market capitalism in varying forms constitutes the dominant system of socio-economic organisation worldwide. It is associated, in Western democracies, with welfare capitalism through links with the welfare state, social insurance and public services, such as education and health care, which are funded through transfer payments.

Historical perspectives on socio-economic transformation have analysed the emergence and transformation of capitalism over time and across space, including in relation to other systems and forms of socio-economic organisation. These have included competing political-economic systems (at one time socialism and central planning). They have also included complementary forms and sectors of economic activity within capitalist societies, such as the welfare state, the 'informal' economy, and the illegal and illicit economies.

An important line of argument from a transitions perspective is that there is a strong political lock-in to the prevailing growth paradigm, owing to the current need in any restructuring to maintain a tax base and to secure jobs and employment. Politicians are locked in to a paradigm of economic growth even when they know this is environmentally damaging and that growth does not necessarily contribute to improving the well-being of the materially poor or to improving the quality of life or happiness of citizens whose basic material needs are met already. Under current socio-economic arrangements, maintaining a strong fiscal revenue base and securing jobs in the formal economy are important politically because these are bedrock elements of the mechanisms and systems of distributing entitlement to a proportion of GDP (gross domestic product) and to enabling welfare capitalism.

Reform or replacement of these mechanisms and systems — for example through the growth of the informal economy, redefinition of work and restructuring of time use in society — may be needed to weaken political lock-in to the growth paradigm. In doing so, such changes could create 'degrees of freedom' for political action in the longer run towards less materialistic models of socio-economic organisation and development.

Various forms of social innovation are already beginning to offer alternatives to mainstream ways of living, working and meeting needs. This explains why it can be interesting to explore the potential contribution of transformative social innovation to sustainable development. Creating viable secondary mutual aid and sharing economies using alternative currencies, time exchange and local resources could offer local security, well-being and resilience to downturns in the formal mainstream economy.

Social innovations are changes in social relations, involving new ways of doing, organising, framing and/or knowing (Haxeltine et al., 2016). They are locally situated and rooted, but also internationally connected in network organisations, which engage in 'diffusing knowledge ..., exercising power and influence ..., building alliances with other societal actors, and securing (or creating) new resources for the network and its members' (Haxeltine et al., 2016).

The activities of social innovators are associated with another phenomenon, that of public intellectuals discussing specific processes of change. The development of a market society is based on the ideas of Adam Smith about the advantages of free (self-regulating) markets, utilitarianism as formulated by Jeremy Bentham and John Stuart Mill, and neoliberalism as an economic ideology, associated with the writings of Friedrich von Hayek and Milton Friedman about markets serving wealth and political freedom. It seems that every socio-economic transformation is associated with the ascendance of certain ideas within the intellectual discourse. In social innovation initiatives — such as transition towns, eco-villages, slow food and downshifting — political philosophies of liberalism (the humanistic version with an important role for self-actualisation and ethics) are combined with communitarianism (the importance of ties and belonging).

The relative importance of ideas versus interests is a much debated issue. According to Campbell (1998), both are important and cannot be reduced to one another: 'ideas provide specific solutions to policy problems, constrain the cognitive and normative range of solutions that policymakers are likely to consider, and constitute symbols and concepts that enable actors to construct frames with which to legitimize their policy proposals.' To this he adds the important point that 'although the influence of organizational resources has a heavy effect on building effective frames, actors build frames from the already existing normative elements that constitute public sentiments, which do not arise simply due to the manipulations of powerful interests' ([5]).

Addressing the neoliberal paradigm

Meanwhile, the neoliberal project is both 'alive and kicking' and under attack. The market is blamed for many of today's ills: environmental degradation, hedonism, economic insecurity, social exclusion and the loss of social bonds. A diverse mixture of responses are proposed, ranging from radical change to reform of the economic system.

The New Economics Foundation, for example, proposes a 21-hour workweek, as a new cultural standard for addressing a set of interlinked problems. These include 'overwork, unemployment, over-consumption, high carbon emissions, low well-being, entrenched inequalities, and the lack of time to live sustainability, to care for each other, and simply to enjoy life' (NEF, 2010). According to Rosnick (2013), reducing work hours over the rest of the century by an annual average of 0.5 %, would 'eliminate about one-quarter to one-half of the global warming that is not already locked in (i.e. warming that would be caused by 1990 levels of greenhouse gas concentrations already in the atmosphere)'.

The moral imperative of respecting nature is addressed in the encyclical *Laudato Si*, which came out in 2015. In the encyclical, Pope Francis (2015) denounces the 'self-centred culture of instant gratification' and calls for ecological conversion. Scharmer and Kaufer (2013) likewise address the culture underpinning market economies, calling for a shift from 'ego-system' to 'eco-system' economies. In contrast, green growth (see Section 4.4.3) is a more reformist idea, seeking environmental protection through capitalistic forces.

Transformation of the economy may also necessitate changes in the role of the state. For creating a more social economy, John Restakis (a commons transition theorist and cooperative activist) wants the state to develop into a 'partner state', by which he means a state that 'salvages what is good and necessary in the apparatus of government while opening it to those civic values that alone can restore legitimacy to it' (Restakis, 2014).

A similar call comes from Will Hutton (2015), who contends that the state should be less 'a directive sovereign over us' and more 'a co-creator with us'. Hutton, a regime insider, is very critical of shareholder

([5]) Practice theorists distinguish a third factor: practice as a source of agency (Carstensen, 2011).

capitalism for not living up to its responsibility to contribute to the common good. He argues for a new approach to ownership in the form of a Companies Act for the 21st century, which 'sets out unambiguously what society expects from companies in exchange for the privileges they are afforded'. The act would require that companies 'declare their business purpose on incorporation', indicating whether their purpose is shareholder value maximisation or being a for-benefit company that goes beyond what is legally required, so that this become clear for workers, consumers, investors and the government.

4.3 Understanding and conceptualising transformations

Sections 4.1 and 4.2 of this chapter outline a variety of ways in which socio-economic systems and the dominant socio-economic paradigm produce undesirable and unsustainable outcomes. These point to the need for systemic change in a variety of areas:

- countering the marketisation of society and the commodification of labour, land and money, which has distorted our understanding of human nature and the core values underpinning society (e.g. consumerism, materialism);
- correcting government and policy failures (e.g. lobbying, vested interests, rent-seeking), which are possible because of policy paradigms that favour economic growth over environmental preservation;
- dealing with market failures linked to, for example, allocation of property rights, transaction costs, the non-internalisation of negative externalities of pollution and depletable resources not being properly priced, resulting in extensive resource use, emissions, social harms and misallocation of investment;
- correcting information system failures in the dominant systems used to support economic decision making, such as the system of national accounts, and reviewing underpinning assumptions and practices in economic modelling, such as time discounting in benefit-cost calculations that introduce systematic bias;
- transforming the money economy that is currently geared towards speculation, externalisation of risk by financial institutions and incentivisation of risk taking.

This section explores these transformation processes.

4.3.1 What kind of processes are socio-economic transformations?

The literature on transformation does not provide a list of processes of socio-economic transformation but an important role is attributed to marketisation, path-dependency, conflict and pacification, and the interaction of the local with the global. According to Marx, the economic base (i.e. forces and relations of production) determines society's superstructure, including people's beliefs and consciousness. However, this appears to be too simple a view. People are part of historical processes, and marketisation — the spread of market thinking and market-based forms of allocation throughout society — is an important one.

Socio-economic transformations are about change in work, human aspirations and forms of protection. In pre-industrial times, much economic activity was in agriculture and cities. The market was a physical place. Work was based on tradition and on property relations, with an important role for family businesses and collective use of land. The relationships shifted at the time of the industrial revolution. In his book *Origins of our time: The great transformation* (1944), Polanyi offered a critical discussion of market liberalism and utilitarianism and how this led to the commodification of labour, land and money. The commodification process led organisations and individuals to exploit nature and humans as a means to an end, supplanting kinship, custom, religion, morality and community-based forms of living and decision-making.

The marketisation of the economy was based on the philosophy of classical liberalism, which attributed a positive role to individual freedom. In *The wealth of nations* (1776), Adam Smith argued that the pursuit of self-interest in free-market exchanges would promote the wealth of a society better than if people tried to improve it directly out of altruism for the sake of the common good. Capitalism changed modes of production and work relations. Initially, the 'social relationships between capitalists and workers ranged from various purchase arrangements in which producers owned the tools, premises, raw materials and finished goods to various putting-out arrangements in which the merchants owned some or all of them' (Tilly, 1992). Over time, workers became less the masters and owners of their work and tools, but labourers 'in large shops under centralised time-discipline.'

According to Tilly, the emergence of capitalism brought with it a shift in social relations, driven by a multitude of factors. New technologies contributed to this change but the causality ran in both directions: 'Although new technologies certainly contributed to the fixing,

disciplining and intensification of labor, much of the nineteenth-century expansion of production preceded the spread of the factory and assembly line, occurred without substantial change in the actual techniques of production, and depended mainly on alterations in the social relations of production. In textiles, chemical and metal production, technical innovations promoted dramatic increases in the scale and intensity of production. For manufacturing in general, two essentially social innovations played a larger part in transforming production: first, the grouping of workers in large shops under centralized time-discipline; and second, the monopolisation of means of production by capitalists' (Tilly, 1992).

A more analytical account of the interaction of technology and social relations is offered by Freeman and Louçã (2001) in the form of a model of co-evolution of five sub-systems of society: science, technology, economy, politics and general culture. The sub-systems are entangled with one another and the classification is said to be a simplifying classificatory framework: 'the political and cultural milieu ... powerfully influence the evolution of the economy, as they also, reciprocally, influence the evolution of science and technology'. The framework is used to explain growth differentials and economic development by focusing attention on historical underpinnings. The authors criticise models of technological determinism (where new technologies provoke changes in social relations), economic determinism (which treats prices as the agents of change) and models of cultural determinism.

Protection was afforded through different institutions: families, guilds, fraternity societies, labour unions and later through state policies. An example of an early state policy is the English Poor Law of 1601, which provided for taxation to fund relief activities (SSA, 2017). The modern welfare state of Western societies developed from this. The welfare system underwent change, in terms of restricting access and accelerating exit, segmentation of participants, introduction of contractual obligations and application of diverse incentives for recipients of public assistance, disability and unemployment benefits (Gilbert, 2005). The marketisation process is very much amplified by the increasing influence of financial markets, which reduces the autonomy of state-nations (Rodrik, 2011b). But rather than being an autonomous force, marketisation also sparked reactions in the form of demands for protection and reform, and humanisation initiatives (Polanyi, 1944; Kemp et al., 2016).

A negative element of marketisation is that it fuels competition in the social and economic realms. Competition in the marketplace drives organisations towards short product cycles (planned obsolescence) with excessive exploitation of natural resources, and fuels consumerism through advertising and by holding up materialistic images of success and pleasure. Another development that operates via marketisation is meritocracy. Meritocracy developed from a justified call to a force of self-discipline: by putting pressures on workers to be productive and flexible under the threat of job loss. People are made into competitive persons: 'a neoliberal meritocracy produces its own assumption of universal egotism' (Verhaeghe, 2014).

While the above discussion highlights the negative aspects of marketisation, it is worth noting that people in rich countries report higher scores for happiness (Hagerty and Veenhoven, 2003), which is no doubt related to material wealth and to welfare policies. Nevertheless, obtaining that wealth came at a cost, in the form of environmental degradation, job uncertainty, unemployment and exclusion, the uprooting of people and the undermining of state sovereignty.

Values and cultural factors

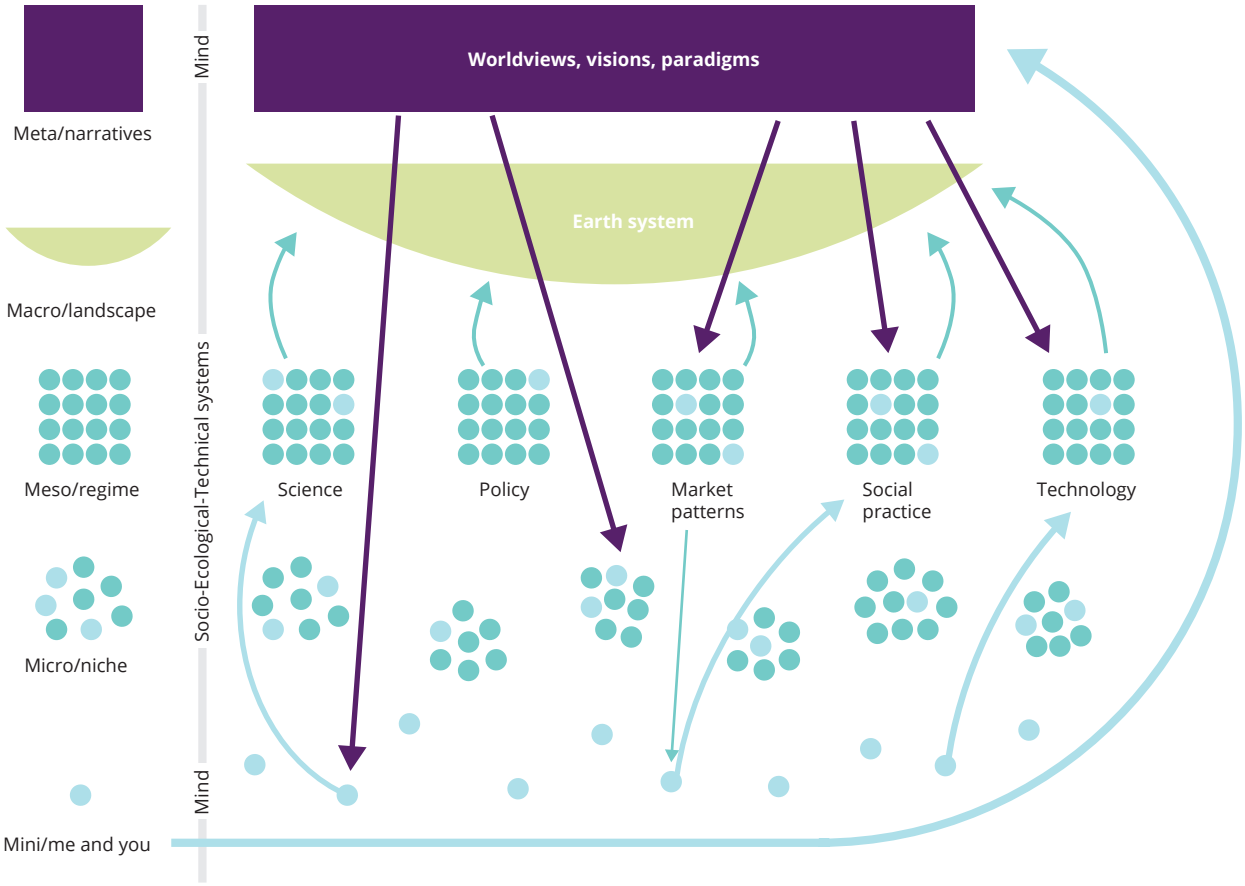
There are many different perspectives offered on the drivers of marketisation and consumerism, and some debate over the role of capitalism, global institutions and the market, on the one hand, versus the spread of status rivalry, which becomes enacted through conspicuous consumption, on the other hand.

In the book *The great mindshift*, Maja Göpel (2016) offers an interesting reformulation of the multi-level perspective, by adding the layer of inter-personal relations (at the level of individuals) and separating the landscape from a layer of worldviews, visions and paradigms, which are related to individuals as reflective persons, and the level of regimes and niches as socio-technical constellations (Figure 4.1).

While values and cultural factors are clearly important, the relationship between value formation and capitalist institutions and other aspects of mainstream socio-economic organisation are complex. There are longstanding debates over the extent to which individuals have free choice to determine and express their values (agency) or are constrained by institutions (structure).

According to Karl Marx, 'Men make their own history, but they do not make it as they please; they do not make it under self-selected circumstances, but under circumstances existing already, given and transmitted from the past' (Marx, 1852). When institutions are viewed as unfair they become a source of criticism and subject of attempts to reform. The struggle for reform may be pursued under the banner of a big societal

Figure 4.1 Reformulation of the multi-level perspective with 'me' and 'you'



Source: Göpel, 2016.

ideology, such as Marxism, or through more concrete, practice-oriented narratives. Social change initiatives are aware of the power of narratives and spend time and energy crafting narratives to, on the one hand, co-exist and compete with the currently dominant narratives pertaining to the neoliberal world order (e.g. the need for economic growth) and, on the other hand, guide and inspire own-action strategies. These counter-hegemonic narratives may propagate notions of resistance, of heroic change makers or of resilient communities (Wittmayer et al., 2015).

Processes of institutional change

Economic systems operate on varying levels of scale and interact across scales. Mechanisms for transformation are often local, but working within (or against) frameworks established at higher scale levels. Whereas socio-technical transitions take place over decades (Geels, 2005a; Grin et al., 2010a), transformations of society's formal and informal institutions take even longer (Williamson, 2000). The transformation process will differ across time and space, as shown by the existence of varieties of capitalism (Hall, 2001; Hall and Gingerich, 2009).

Socio-economic transformations are conceptualised here and by others as multi-agent, complex, long-term processes of re-institutionalisation. Institutional theorists offer some insights into the institutional element in societal change processes. In this literature there is a tendency to view change either as adaptive or transformative, where transformative change is seen as rare and sudden, and is typically caused by external events. Streeck and Thelen (2005) criticise this bifurcated view of institutional change, arguing that far-reaching change may stem from 'the accumulation of small, often seemingly insignificant adjustments'. They propose to distinguish processes of change from the result of change (Table 4.1). The spread of market relations in modern societies is an example of transformation that is neither abrupt as a process nor minor in terms of its outcomes.

Table 4.1 Types of institutional change: processes and results

	Resulting in continuity	Resulting in discontinuity
Incremental processes	Reproduction by adaptation	Gradual transformation
Abrupt processes	Survival and return	Breakdown and replacement

Source: Streeck and Thelen, 2005.

'Dramatic institutional reconfiguration' may occur 'beneath the surface of apparent stability or adaptive self-reproduction' (Streeck and Thelen, 2005). Abrupt events (such as a crisis) may trigger a breakdown and replacement, but they may also fail to do so. Rather than being caused by external events, the authors say that a transformation may emanate from ambiguities and gaps that exist within a regime, and the interaction with other regimes. As they write, 'Political institutions are not only periodically contested; they are the object of ongoing skirmishing as actors try to achieve advantage by interpreting or redirecting institutions in pursuit of their goals, or by subverting or circumventing rules that clash with their interests. Instead of separating institutional development into periods in which agency matters more than structure or the other way around, the aim must be to understand, as Deeg puts it, the way actors cultivate change from within the context of existing opportunities and constraints — working around elements they cannot change while attempting to harness and utilize others in novel ways' (Streeck and Thelen, 2005).

Institutional arrangements at any time are never completely coherent and, as such, they are subject to transformation. Non-abrupt institutional transformation may take five forms. Subordinate institutions may gain dominance (displacement), new elements attached to existing institutions may gradually change their status and structure (layering), neglect of institutional maintenance in spite of external change may erode institutional practices (cause a downward drift), existing institutions may be redirected to new goals, functions or purposes (conversion), or institutions may wither away (exhaustion) (Streeck and Thelen, 2005).

4.3.2 Transforming the socio-economic paradigm: a three-movement model

Historical change consists of complex junctures and tensions that give rise to dialectic dynamics between different logics. A recent paper by Kemp et al. (2016) on 'humanisation' of the economy through social innovation (which provides the basis for this discussion), systematises the interplay between the logic of marketisation, state-based protection and humanisation initiatives, into a three-movement model. The double-movement model of Polanyi (of marketisation and social protection) is reformulated to include: marketisation, state-based social protection and the humanisation of the economy.

The 'humanisation of the economy' process is believed to be partially a response to de-humanising aspects of marketisation and bureaucracy but also a re-articulation of a historical phenomenon. Transformative social innovation initiatives deploy an 'unconventional' modus operandi that is different from mainstream organisational logics. Their organisational cultures are typically less formal and less hierarchical than those of mainstream organisations. Political philosophies of liberalism (the humanistic version with an important role for self-actualisation and ethics) and communitarianism ([6]) are combined (to different extents in specific cases). Humanisation activities are related to basic psychological needs for autonomy, relatedness and competence ([7]), which are being undermined (less catered for) by marketisation and bureaucratic systems based on formal rules and managerialism.

([6]) 'Communitarianism' sees social attachments and communities as integral to well-being by offering people identity in a socially rooted, purposeful way.

([7]) 'Autonomy' means to act in harmony with one's integrated self (based on intrinsic motivations); 'relatedness' is about feeling connected to others and caring for others; and 'competence' is the ability to control the outcome and experience mastery (Sheldon and Ryan, 2011).

Whereas economic liberalism was supported by the trading classes, the third movement is supported by those who are disenchanted with current arrangements for work and the welfare state and seek to enhance human well-being through autonomy-enhancing solutions.

The third movement consists of collective forms of living and work, local resilience initiatives (such as transition towns and urban gardens), commons-based forms of production (co-maker spaces and peer-production), practices of permaculture and slow food, and autonomy-based forms of work in the market economy. Environmental motivations are important in several initiatives, but values of communality and self-actualisation also play an important role ([8]).

In terms of transformation, the three-movement model distinguishes two types of transformation: the transformation of society into a market society, and a much weaker transformation of the economy-society-nature relationship into a more humane, 're-embedded' rather than dis-embedding, relation, where human and environmental well-being are more fundamental than the maximisation of private profits. It is aided by cheap digital technology, models of cooperative production and models of sharing space, land, tools and goods, and service trading (e.g. through time exchange mechanisms and informal systems).

Humanisation as a movement is understood as a force that plays out within and across each of the three sectors: market, state and civil society (Table 4.2).

The humanisation process of transformative social innovation is believed to have declined during the expansion of the welfare system but has expanded since the 1990s, with a proliferation of initiatives in the last 10 years in the West (Figure 4.2).

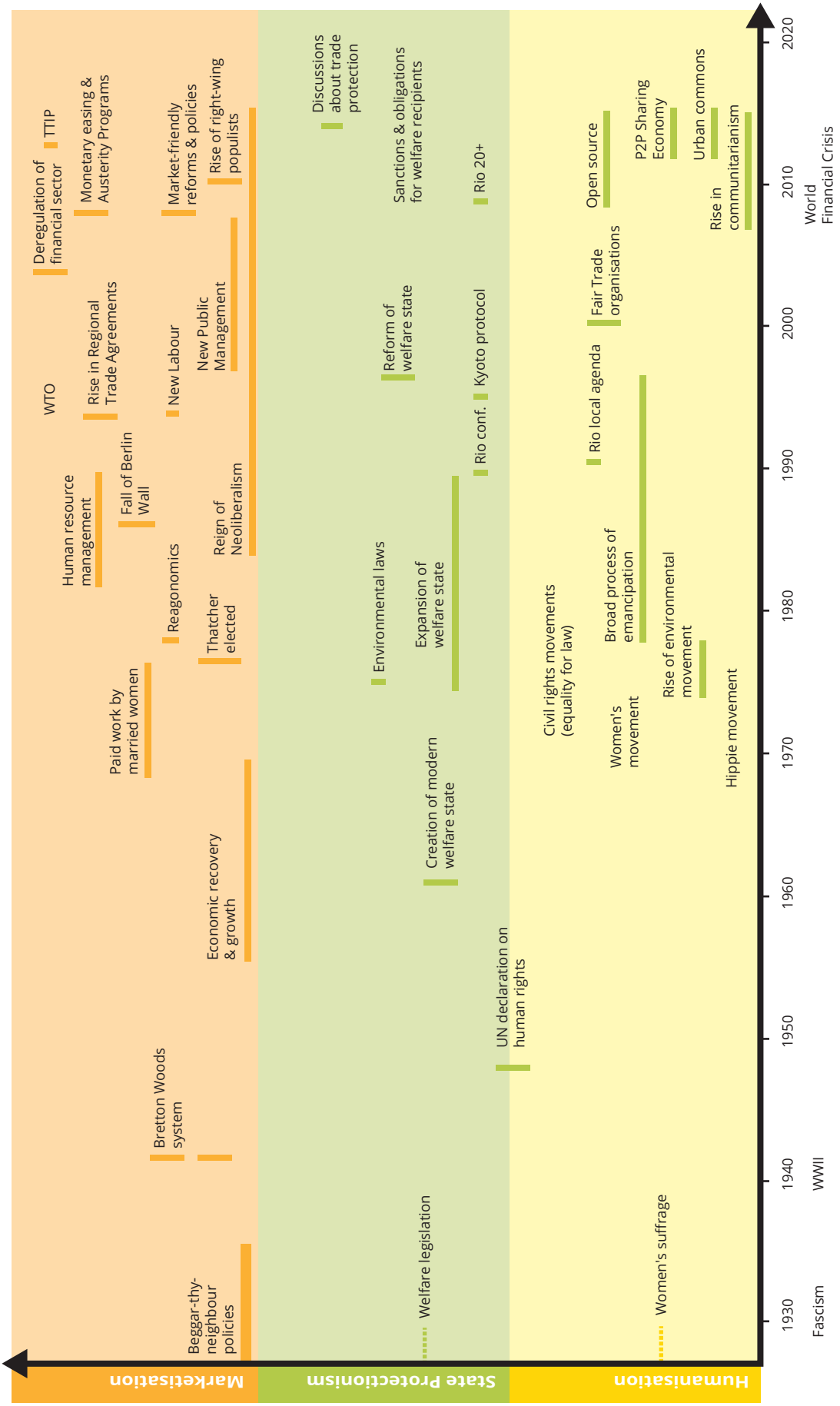
The environmental gains from a further expansion of third-movement activities are difficult to estimate but may offer some direct potential benefits if these can be scaled up: for example, eco-villages based on permaculture; slow food based on organic, local and seasonal food; and renewable energy cooperatives. For example, carbon dioxide (CO_2) emissions from people living in eco-villages in Germany are found to be substantially below those for an average German (Figure 4.3).

Table 4.2 Marketisation, state-based protection and civil-based socialisation, as expressed in de-humanised and humanised versions

	Less humanised or de-humanised version	Humanised version
Marketisation	A private profit market (solely shareholder values)	A social market (stakeholder and stewardship values)
State-based protection	An overly bureaucratic, disabling state: traditional welfare leading to poverty trap and forced employment (based on distrust and paternalistic control)	A facilitating and enabling state, offering training and coaching, a basic income and participatory budgeting (based on trust and letting go of full control)
Civil-based socialisation with forms of association based on relatedness and social purpose	Disempowering forms of egalitarianism in which 'some are more equal than others' or autonomous and efficient decision-making is overshadowed by excessive consensus and shadow hierarchies	Empowering forms of cooperatives, social enterprises, non-governmental organisations, etc.

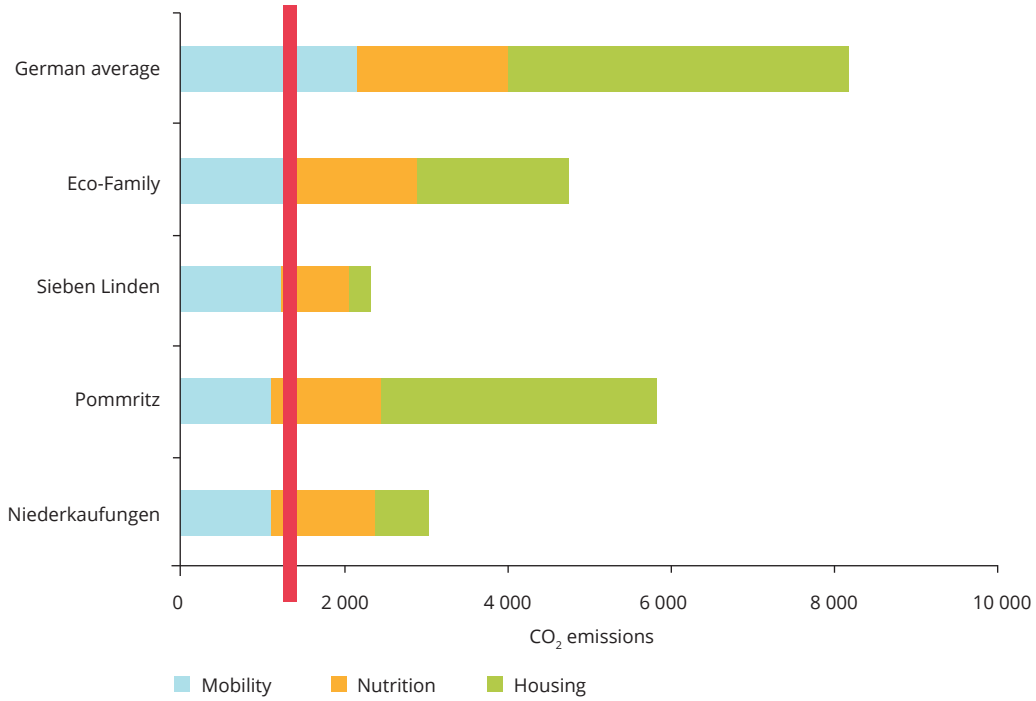
([8]) Eco-villages are places for self-realisation and for strengthening immaterial values such as enjoying nature, community and cultural and creative life (Kunze and Avelino, 2015).

Figure 4.2 Historical dynamics of marketisation, state protectionism and humanisation



Source: Kemp et al., 2016.

Figure 4.3 Per capita CO_2 emissions of four German eco-villages compared with the German average



Source: Simon et al., 2004.

Positive effects can also be expected from working less in the market economy and the creation of an alternative economy based on repair, sharing of goods and open source models of production. However, the influence of third sector and commons-based activities may be more indirect, for example, by averting consumerism and helping spread an alternative vision of a good life. The creation of second-level economies may also be important for freeing up the options of political leaders with respect to reform of mainstream markets and their institutions, as a functional second-level economy and welfare system would help reduce dependence on the mainstream systems. It could thereby reduce pressure on political leaders to prioritise securing the tax base and jobs over environmental protection.

4.3.3 Transforming socio-economic sub-systems

Correcting market failure: benefits and limitations of ecological fiscal reform

The conventional approach to correcting market failure with respect to excessive environmental damages is based largely around the concept of 'internalising' costs that are external to the market. However, there are serious limits on what can be achieved through this approach in terms of the technical feasibility of quantifying externalities across huge spatial and temporal scales, the governance challenges (e.g. public reaction, distributional impacts, free-riding, etc.) and practical problems with a shrinking tax base and substitution effects, among others. A more fundamental criticism is that the notion that correcting resource management and pollution is just a matter of 'getting the prices right' does not question the primacy of markets (and the associated values). Indeed, monetising environmental damage arguably entrenches marketisation further.

Taxes (since the 1980s) and cap-and-trade instruments (since the 1990s) have often been seen as preferable to regulatory policies on grounds of greater economic efficiency and lower administrative cost. Efficiency gains in meeting environmental policy targets are a function of differences in the costs facing economic actors. The greater the cost differences, the greater the scope for reducing the aggregate cost to society of achieving environmental protection at a desired level. Indeed, the transition from the early reliance of environmental policy on environmental regulation (command and control style policy) to using economic instruments can be considered a first transition in environmental policymaking.

This process has continued as increasingly more policy-integrated approaches to environmental

protection have been adopted. A 'next step' was the concept of ecological tax reform. This arose partly from the resistance found to environmental taxes on grounds that these can depress economic growth (with negative impact on or gross national product, employment levels, tax revenues, etc.). They can have regressive social impacts by increasing the cost of basic necessities, such as energy and water, for the poorest in society for whom such basic necessities form a relatively bigger proportion of their overall consumption than for those who are richer. Environmental taxes faced resistance, therefore, on grounds of both stymying economic growth and social justice.

The logic of an ecological tax reform is to shift the burden of taxation from environmentally and socially 'good' functions to 'bad' functions (i.e. away from social charges on employment and on to resource extraction, pollution, and consumption of eco-intensive goods and services). In addition to rewarding resource efficiency, recycling and clean technology investment/innovation, ecological tax reform incentivises sustainable consumption of low-carbon energy, dematerialised products and immaterial services, rather than material goods.

Ecological tax reform has been practised to a limited extent and with success since the mid-1980s, but its significance has recently increased in the context of efforts to stimulate green growth and transition to a green economy. Recommendations for environmental fiscal reform, for example, feature in EU fiscal and budgetary policies, in the European Semester process of the Europe 2020 strategy and in country-specific recommendations of the Annual Growth Survey as a means to foster resource efficiency and economic transition (Speck, 2015).

Growing support for tax reform reflects progressively deepening recognition within the EU policy process of the systemic nature of environmental policy, which is reflected today at all levels of EU policy (Speck, 2015). However, concerns have been expressed over the potential for reconciling the different timeframes for economic and social policy challenges (relatively short term) and the longer term perspectives needed for environment and climate policies (Meadowcroft, 2009).

While taxes have a positive role to play, Speck (2015) questions whether increases in energy tax rates and a high carbon price would enable governments to sustain environmental tax revenues as a share of GDP, let alone increase them as proponents of environmental fiscal reform envisage. In the transport sector, for example, the EU has established a policy goal to achieve a 70 % reduction in oil consumption across the EU by 2050 (from 2008 levels). This implies that carbon taxes would need to increase annually by more than 4 % to keep transport oil tax revenues constant as a proportion of GDP. Some country-specific goals for transport energy envisage a 100 % shift to renewable energy (e.g. Denmark), which would completely eliminate the transport oil tax base.

This highlights the kind of governance challenge facing policymaking in the transition to a green economy in selecting appropriate fiscal instruments, packages and sequences. It also highlights the importance of understanding the wider set of policy goals and imperatives facing policymakers, including the critical need to sustain a revenue base.

Reforming finance: managing systemic risks and redirecting investment

Within the framework of the current global financial environment, securing financial investments for mitigating or adapting to emerging sustainability problems is a crucial but complex issue for both policymakers and wider governance structures. There are two major aspects of market and policy failure, namely the socio-economic risks and harms arising from the globalised financial system; and misallocation of financial resources towards environmentally and socially harmful activities. Although these aspects are linked, it is useful first to reflect on them individually.

The rising role of finance in economic development and societal evolution is discussed under the heading of financialisation, 'the process whereby financial markets, financial institutions and financial elites gain greater influence over economic policy and economic outcomes' (Palley, 2007). This may, for example, arise due to financial engineering, such as the creation of second- and third-tier derivatives, or lobbying (Kay, 2015). The economic effects of financialisation are 'to elevate the significance of the financial sector relative to the real sector; transfer income from the real sector to the financial sector; increase income inequality and contribute to wage stagnation' (Palley, 2007).

Underlying both contemporary financial instability and transformation is the question of what financial institutions do, or are permitted to do, with other people's money. Since the 2008 crisis, economists and other researchers argue increasingly in favour of separating high-risk 'casino' investment banking (e.g. derivative-market speculation) from traditional banking (e.g. holding savings, issuing loans and mortgages, and providing daily transaction services to individual customers and businesses), to protect

local economies from global instability (de Bettignies and Lépineux, 2009; Werner, 2014; Douthwaite, 2012). However, governments of Organisation for Economic Co-operation and Development (OECD) countries have been slow in implementing such regulations, while the Bank of International Settlements has made recommendations for stabilisation improvements that are, so far, only voluntary (Beachy, 2012).

At the same time, there is growth in green finance and the use of sustainability criteria by institutional investors. The potential for scaling up green finance is substantial, partly because it is rather small. According to a G20 report, 'only a small fraction of bank lending is explicitly classified as green according to national definitions. Less than 1 % of global bonds are labelled green and less than 1 % of the holdings by global institutional investors are green infrastructure assets' (GFG, 2015).

4.3.4 Empirical examples

Consumerism and counter-movements

Research by Jeanine Schreurs (2010) into the effects of 'downshifting' (voluntarily or involuntarily decreasing consumption) in the Netherlands revealed some remarkably positive results (Figure 4.4). Many positive effects included 'becoming less attached to material possessions', 'increased self-esteem, confidence and pride', and experiencing 'making ends meet as a positive challenge'. Reported negative effects were fewer in number and also less pronounced than the positive effects. Strikingly, this was even true for the involuntary downshifters.

In terms of the greenness of their behaviour, the study found with high probability ($p < 0.01$) that downshifters were significantly more economical with energy than non-downshifters. The main reduction in environmental pressures can be expected to come from reduced spending.

The results on downshifting lend some support to Jackson's conjecture that 'If social and psychological needs really are ill-served by modern commodities, then it should be possible to live better by consuming less, and in the process reduce our impacts on the environment' (Jackson, 2005a).

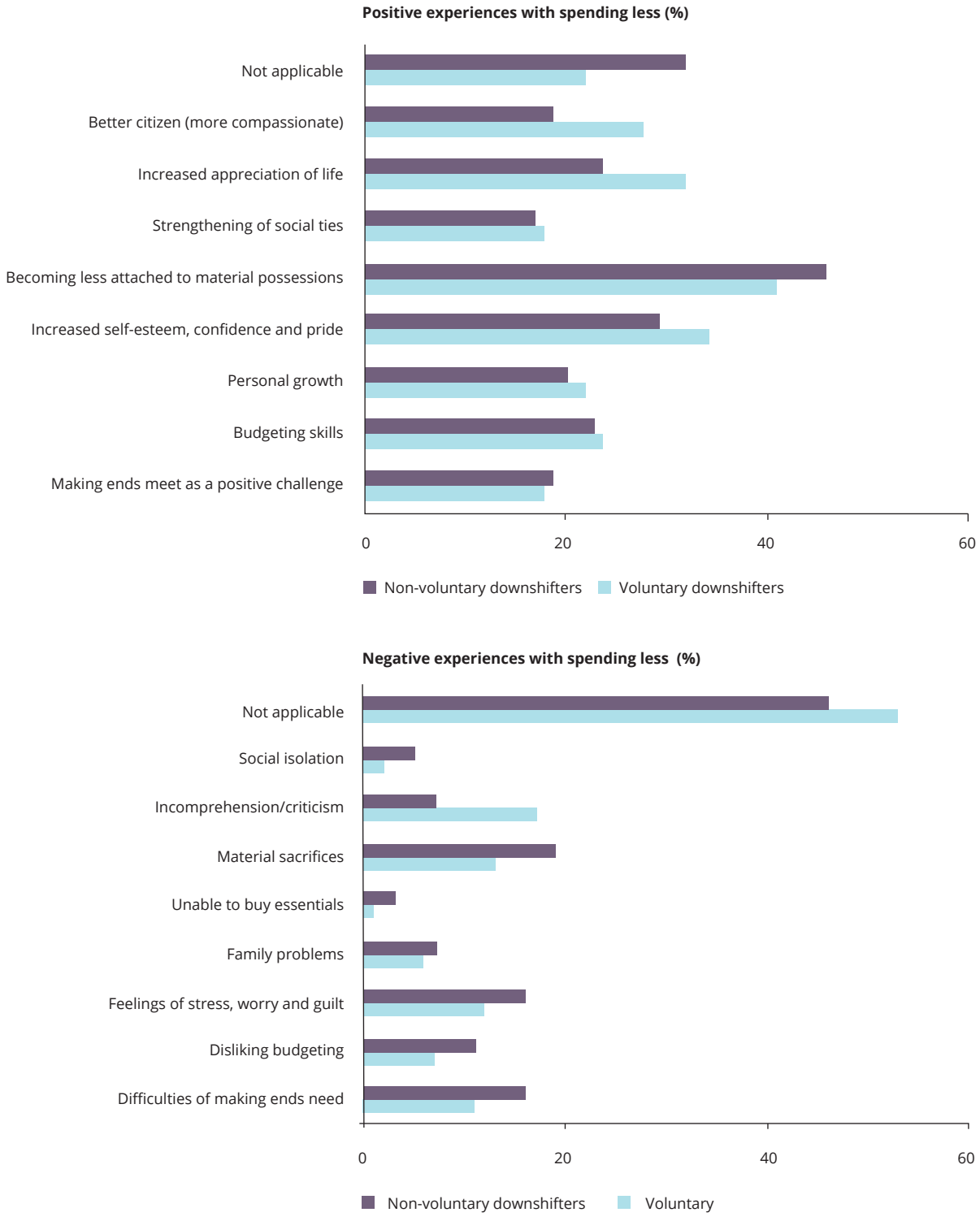
In recent work with others, Juliet Schor studied new forms of consumption, with special attention to 'connected consumption' based on peer-to-peer relationships rather than existing market actors to mediate exchanges. Schor and Fitzmaurice (2015) offer a typology of peer-to-peer types of consumption based on whether the transaction is profit oriented and involves business. The authors state that connected consumption is motivated by economic and ecological concerns, as well as by a desire to increase social connections. However, environmental gains may be small in the absence of downshifting. Ecological aims may also obtain less attention over time. For example, Zipcar, a for-profit form of car sharing, originally aimed to reduce carbon footprints but its partnership with the Ford Motor Company involved offering sport utility vehicles. It was also noted that the decision of Zipcar 'to put cars on college campuses, where cars were rare, may end up increasing car use, rather than reducing car usage' (Schor and Fitzmaurice, 2015).

The sharing economy is promoted as a means to reduce use of materials. However, outcomes ultimately depend on how the sharing economy is shaped and framed, suggesting a role for transition thinking in any policies intended to promote the emergence of a sharing economy. Sharing is subject to rebound effects unless the sharing is associated with downshifting. In general, practices that save costs, such as collaborative forms of production and non-motorised forms of transport, are subject to rebound effects, which stems from extra consumption made possible by avoided expenditure (Vivanco et al., 2015).

In a highly utopian discussion, Paul Mason talks about 'post-capitalism' as a new stage of economic development, based on the socialisation of capital and cooperative production by citizens with the help of cheap information technology. He notes that barriers to production are being reduced as a result of cheap computing and communication, and new technologies, such as 3D printing, in combination with models of peer production ([9]). In the future, (more) people could turn away from brand products and salaried jobs in the market economy and opt for more cooperative ways of work and living based on values of mutuality and care for the environment. According to some observers, millennials (i.e. people born in the 1980s and 1990s) value experiences over possessions more than previous generations (Morgan, 2015). However,

([9]) Peer production occurs when people cooperate voluntarily on an equal footing (as peers) to reach a common goal. Examples of commons-based peer production are Wikipedia, open source software and material goods, such as architectural blueprints for houses, construction plans for agricultural technologies and designs for 3D printed objects.

Figure 4.4 Positive and negative experiences of voluntary and involuntary downshifters



Source: Based on Schreurs, 2010.

this may be a temporary effect that holds true only for high-income countries.

Alternative currencies

Broadly, any socio-economic exchange system constitutes some form of currency. As such, units of almost anything can effectively be used as money, if mutually regulated and agreed upon (Boyle, 2014). Although multitudes of exchange systems have come and gone throughout history (Mellor, 2005), recent decades have seen an expansion of 'alternative currencies' (also known as 'parallel', 'community', or 'complementary' currencies in different contexts). This expansion was particularly apparent towards the end of the 20th century among rural and community movements aiming to improve local social, economic and ecological resilience, and thereby increase local autonomy. More recently, 'alternative' currencies have provided a way to reduce the exposure of local economies to global financial volatility or economic growth imperatives.

The first local exchange trading system (LETS) using an alternative local currency was created on Vancouver Island in 1983 in response to economic recession. Similar systems soon appeared in the United Kingdom, Australia and New Zealand, followed by Germany and France in the 1990s (Dittmer, 2013). The most well known local/parallel currency is perhaps Ithaca HOURS, created in 1991 in New York. Many more now exist, for example the Bristol Pound in the United Kingdom and the Chiemgauer in Germany (Dittmer, 2013).

Time banks also operate as mutual exchange systems, but, instead of using a locally issued paper or coin currency, they use time as the medium of exchange

Table 4.3 Generalised typology of community currencies

Category	General objectives/purported benefits	Examples
Service credits	Co-production of community social-economic-environmental objectives; build social networks and capital; improve community cohesion and inclusion.	Time banks • London Time Bank Network (UK) • Stealwear Time Bank (UK) • TidsNätverket i Bergsjön (TNB) (Sweden)
Mutual exchange	Provide additional liquidity; ease access to interest-free credit; encourage import substitution; community building (e.g. social capital).	LETS • North Herts LETS (UK) • RozLEŤSe (Czech Republic) • Tauschringe (Germany)
Local/parallel currencies (a)	Improve local economic development (e.g. supporting local business); retain money circulation in local economy. More recently becoming electronic rather than paper, increasingly well marketed.	Non-convertible local currencies (not backed by legal tender) • Ithaca HOURS (USA) Convertible regional currencies • Bristol Pound (UK) • Rubi (Brazil) • Chiemgauer (Germany)
Barter markets	Foster a solidarity economy; encourage environmental behaviours (e.g. sharing, reuse and recycling).	Mixed and ad-hoc barter/local currency systems • Bow Chinook barter community (Canada) • Crédito (Red de Trueque) (Argentina) • Informal internet exchange (such as bartering via social media)

Note: (a) LETS can be considered 'local currencies', depending on particular definitions. Here we refer to local/parallel currencies specifically as a local form of money that is usually exchangeable for national currency. Michel and Hudon (2015) define LETS as service credits.

Sources: Derived from Michel and Hudon (2015), Seyfang and Longhurst (2016), Dittmer (2013), Fraňková et al. (2014) and Boyle (2014).

and unit of account. Time banks were first developed in Japan in the chaotic period immediately after the Second World War in response to the collapse of mainstream institutions (the economy, government, fiat money, etc.). They were separately also developed in the United States by women in and around St Louis seeking to sustain local services in the wake of cuts to public programmes in the 1980s. Time banking was promoted by Edgar Cahn, a civil rights lawyer. Martin Simon and David Boyle pioneered UK time banks in the 1990s. Broadly, European time banks have evolved from alternative currency movements (Boyle, 2014).

The existing research into alternative currencies and time banks is relatively sparse and fragmented. Table 4.3 presents a simple typology covering most community currencies, taken from recent literature. The more successful and widespread initiatives are mutual exchanges and local/parallel currencies. They are diverse, non-standard and usually exist at a small or micro-scale, but share certain features. In particular, they share a general objective of improving local socio-economic conditions by keeping a larger part of savings and local income circulating within the community rather than being extracted to the regional, national or global level (Boyle, 2014; Dittmer, 2013; Douthwaite, 1998; Fraňková et al., 2014; Michel and Hudon, 2015; Pacione, 1997; Sanz, 2016; Seyfang and Longhurst, 2016; Weaver, 2014; Weaver et al., 2015).

If community currencies can improve localised production, consumption and other socio-economic activities, they have strong potential for improving sustainability by supporting more circular economies (Weaver, 2014) and opening opportunities for less materialistic and healthier lifestyles that offer non-material sources of satisfaction, such as autonomy, inclusion, companionship and respect (Weaver et al., 2016b, 2016a).

A recent development in finance is the rise of internet-based 'cryptocurrencies'. These are among the most controversial alternative (parallel) currencies, which support various Fintech innovations. Generated in 2009, Bitcoin (BTC) was the first 'cryptocoin' and remains the dominant example of this technology, although hundreds of variants now exist (Vora, 2015).

Fundamentally, cryptocurrency technology offers transparent transfer of ownership of (potentially) any asset, due to their extremely robust built-in encryption algorithms and shared transaction record. Intrinsic to cryptocurrency software, every user must have the same transaction database for the system to function (Böhme et al., 2015). As with any currency, they can be used to support local green energy projects and local activities more generally, but without the involvement of centralised banks.

Shares in community-owned facilities can be traded, transparently, on the Ethereum platform (DeMartino, 2015). Created by a Swiss not-for-profit foundation, Ethereum offers a platform for customised cryptocurrency, enabling any user to generate their own secure and encrypted transaction database application, for virtually any purpose.

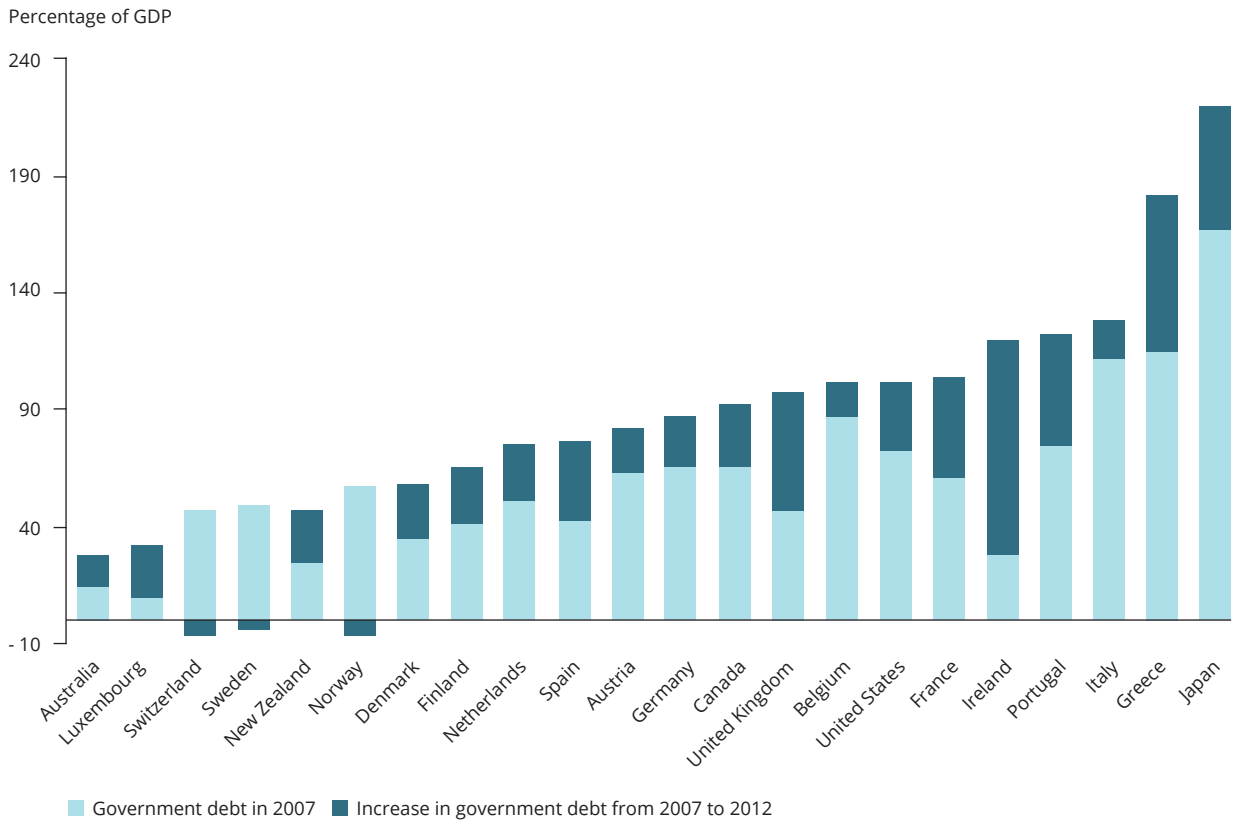
Although cryptocurrencies and related innovations are expanding a new decentralised market for currency, assets and other transaction records, they are not currently expected to replace existing monetary systems. Instead, they will complement them as systems offering low (near-zero) transaction costs. In principle, they could also support the development of small-scale, local economies, such as that being pioneered in the city of Kingston-upon-Hull, United Kingdom (Weaver et al., 2016a).

4.3.5 The future of capitalism

Capitalism is deeply ingrained in modern societies. The free-market economy is even included among the fundamental principles of the EU. According to Polanyi (1944) and Sandel (2012), our society has become a market society. The ascendance of a market society is partly the result of the ideology of neoliberalism and partly the result of self-reinforcing processes, such as global competition leading governments to reduce corporate taxes and reform the welfare state.

Market-based mechanisms can be used for environmental protection but the possible negative effects on competitiveness prevent many governments from using pollution taxes and emission trading systems, despite the efficiency benefits. The dissolution of capitalism seems unimaginable, yet excessive speculation has historically caused market economies to fall apart because of lack of profitable investments and social unrest (van Bavel, 2016). Today, leading politicians in the United States and elsewhere are taking up calls for trade protection and opposition to trade agreements such as the Transatlantic Trade and Investment Partnership (TTIP). A new era of capitalism could emerge, with greater protection aimed at preserving Western lifestyles and new forms of work and living based on cooperation.

Figure 4.5 Increase in government debt after the financial crisis



Source: Streeck (2013) based on OECD Economic Outlook, Statistics and Projections database.

Opposition to authority in Europe and the rise of identity politics in Western societies makes those countries less governable from the top. The consequences for environmental protection are unclear. They are co-determined by international politics, which are influenced by the international political economy, state policies and policies at lower levels, and 'humanisation of the economy' initiatives. According to Jan Rotmans (2013), 'we are not living in an era of change but in a change of era'.

The financial crises of 2007 and 2008, and the ensuing economic turmoil, greatly deepened the level of government debts (Figure 4.5), which could contribute to future crises and major upheavals.

4.4 Governance

Governance of transformations to sustainability represents a hugely complex challenge, requiring coherent activities across multiple sectors and scales. New technologies alone will not deliver transformations to sustainability. As Mazzucato and Perez (2014) note, for example, 'renewables alone do not constitute a synergetic technology system that results in a long wave for the economy'. A green long wave 'golden age' (Perez, 2013), would need to include 'conservation, pollution control, reduction of material content per product; designing for durability; replacing products, possession and waste with services, rental and maintenance and recycling, respectively; promoting the flourishing of the creative economy; making cities more liveable and less polluting; revamping transport systems and the built environment; promoting collaborative and sharing economies; focusing on health (including preventive and personalised medicine); and promoting all forms of education, in and out of schools' (Mazzucato and Perez, 2014).

In the face of such complexity, there is a continuing shift from government by central (state) authority to forms of networked governance for dealing with collective problems, such as climate change and management of common assets (e.g. community forests). This has been accompanied by growing self-regulation and self-governance by business, for example in the form of supply-chain management with third-party certification.

The move towards networked governance as a model for implementation and innovation does not lessen the need for decentralised participants to have an enabling framework to guide decisions and actions towards sustainability. Creating such a framework is the responsibility of governments, as the only agents with statutory and regulatory powers over framing and constructing markets.

For sustainable development, market-based governance and regulation are essential. The neoliberal regime, globalisation processes and market forces have strong internal dynamics and self-reinforcing feedback mechanisms that drive marketisation. Yet the market frameworks that establish the playing field and rules for competition currently fail to harness the market in ways that could make capitalism and environmental conservation more compatible. They work to exacerbate rather than counteract inherent and systematic distortions and biases, such as those arising from the externalisation of many social and environmental costs. Correcting these requires government action.

As discussed, it is not easy for governments to take such action. Efforts that create greater degrees of freedom for government action — and thereby provide new opportunities for decentralised innovation — may be needed before governments can act more decisively. In the meantime, small but synergistic steps in the direction of market reform can help create room to manoeuvre for decentralised actors and innovators at the niche level (Weaver, 2011).

4.4.1 Managing collective action problems: networks and hierarchies

Institutions for the management of commons have been studied by Elinor Ostrom. As she argues, the economic assumption that 'no self-interested person would contribute to the production of a public good' (Olson, 1965) is plainly wrong: 'Extensive fieldwork has by now established that individuals in all walks of life and all parts of the world voluntarily organise themselves so as to gain the benefits of trade, to provide mutual protection against risk, and to create and enforce rules that protect natural resources' (Ostrom, 2000).

Local communities have proved capable of organising themselves to manage a common resource pool, protect themselves against flooding and against risks of falling ill. Through monitoring and sanctioning, the temptation to free ride on the provision of collective benefits was circumvented or reduced (Ostrom, 1990). As Ostrom notes approvingly, 'increasing the authority of individuals to devise their own rules may well result in processes that allow social norms to evolve and thereby increase the probability of individuals better solving collective action problems.'

In contrast, Ostrom's work on managing the commons sets out eight design principles: define clear group boundaries; match rules governing use of common goods to local needs and conditions; ensure that those affected by the rules can participate in modifying the rules; make sure the rule-making rights of community members are respected by outside authorities; develop a system, carried out by community members, for monitoring members' behaviour; use graduated sanctions for rule violators; provide accessible, low-cost means for dispute resolution; and, build responsibility for governing the common resource in nested tiers from the lowest level up to the entire interconnected system.

Applying these principles at the international scale is clearly difficult. Despite some successes in protecting the global commons via intergovernmental agreements (e.g. protecting the ozone layer and addressing acid rain), climate protection has proved to be a more difficult matter. Nevertheless, in December 2015, 195 countries adopted the first universal, legally binding global climate deal. The Paris Agreement establishes a global action plan to limit global warming to well below 2 °C. While uncertainties persist about implementation, the Paris Agreement does constitute further institutionalisation of climate protection. National priorities and concerns are accommodated by means of comprehensive national climate action plans. In themselves, these 'are not yet enough to keep global warming below 2 °C, but the agreement traces the way to achieving this target' (EC, 2016c).

4.4.2 Adaptive governance and transitions management

Transition management (Rotmans et al., 2001b; Loorbach, 2007) is a model of guided evolution, designed to stimulate system innovation. In the transitions management model of Rotmans, Kemp and Loorbach, government acts as a process manager to mobilise the interest of industry and society in systemic change (Kemp et al., 2007b).

Behind transition management are the following elements (2009):

- making the future more clearly manifest in current decisions, by adopting longer timeframes, exploring alternative trajectories and opening avenues for system innovation and system improvement;

- transforming established practices in critical societal sub-systems within which unsustainable practices are deeply embedded;
- developing interactive processes that enable networks of participants implicated in a particular production-consumption nexus to come together, develop shared problem definitions, appreciate differing perspectives and, above all, develop practical activities;
- linking technological and social innovation, because both sorts of change are necessary;
- 'learning-by-doing' — developing experiments with novel practices and technologies, because initiating change reveals the potential and limits of different approaches;
- tailoring support for technologies to the different phase of the innovation cycle;
- encouraging diverse innovations ('variation') and competition among different approaches (selection) to fulfil societal needs;
- assigning an active role to government in mobilising society to orient change in desired directions.

Visions for the future and details of policy are determined politically but state politics are directed towards system innovation. The transition management frame supports actions that steer society in the direction of system innovation. Opposition from incumbent actors can be observed in every transition process.

Transition management was initially heralded as an enlightened model for long-term government policy, circumventing the rigidness of long-term planning and myopia of markets. Subsequently, however, several observers began to raise critical questions about the democracy of transition policies, the influence of regime actors, the focus on technological fixes, neglect of civil society and local authorities, the multi-scale dimension, and the politics of policy implementation and design (Voß et al., 2009).

The elements of transition management are all useful but there is a need to go beyond technology support and socio-technical alignment. Market processes alone are unlikely to enable well developed systems to be overthrown. Rather, transitions require strong government policies to help phase out non-sustainable technologies, rigorously implemented pollution control policies and innovation support policies (Ashford and Hall, 2011).

Green industrial policy is more for developed countries, as few developing countries can financially nurture infant industries into world industries. They can, however, introduce environmental, energy and economic policies in ways that enable green innovation. Clever policy mixes that address identified barriers (behavioural, practical, institutional and political) can help to phase in green technologies, but they require specific capacities for policymaking, monitoring, evaluation and adaptation (Kemp and Never, 2017).

4.4.3 Governance of green growth strategies

A Green Growth Knowledge Platform (GGKP) was recently established to support policymakers with economic information and policy recommendations for green growth. GGKP is a multi-sector partnership of scientific, business, government, non-governmental and international organisations that develops and offers web-based knowledge resources and organises annual conferences on transition to a green economy. It aims to go beyond environmental taxation, which it considers too narrowly specified, to address a wider range of economic interventions.

The approach is prescriptive and forward looking, focusing on supporting transition to a green economy. So far, intelligence and recommendations are mostly based on theoretical and technical contributions, but the intention is to move increasingly toward evidence- and experience-based policy support. There is an intention to build a research agenda around policy experiments and resulting evidence.

Much is expected from comprehensive and coherent policy portfolios to implement green growth strategies. Arguing that effective policy portfolios to support sustainable green growth and transformation will need to apply a mix of policy instruments, the GGKP annual conference in 2015 examined, inter alia, pricing and fiscal instruments and policies to incentivise transition; regulations, standards and codes to mandate green transformation; and financing and investment instruments to enable transformation (GGKP, 2015).

These findings resonate with analysis by Mazzucato (2013) and Perez (2003, 2013) on the role of finance, public investment and institutional innovation. In a joint paper, they highlight the importance of public investment for business innovation (such as Apple's iPhone), the need for mission-oriented investment in research and development, and the value of tax subsidies combined with demand-side policies for

green transformation. They stress the importance of 'a political choice for growth, convergence and synergies', noting that, 'Once there is a consistent direction — such as green growth can have — both regulation and innovation will tend to converge along a known trajectory and the policy makers' criteria can coincide with those of the business strategist' (Mazzucato and Perez, 2014).

Among the key points and recommendations identified at the GGKP annual conference in 2015, it was noted that:

- carbon taxes are efficient in reducing emissions and pollution but eliminating harmful subsidies should be prioritised, as this can release considerable resources to fund transitions;
- decisiveness and predictability in public policies are essential to signal stability to the private sector and thus promote innovation and investment;
- transitioning to a green economy will require involving finance ministries and other key stakeholders in designing and implementing appropriate fiscal and financial policies;
- there is a need for institution building, especially in matching investors with the right investment environment.

A transitions framing may encourage governments to work more towards long-term transformation, but achieving forceful action will be difficult.

4.4.4 Grassroots governance: a complementary economy?

The relatively small scale of social innovation initiatives (compared with the scale of activity of the formal economy) may lead to scepticism about the rise of an alternative or complementary economy, based on mutuality and fairness. However, alternatives to the mainstream economy already exist and it is conceptually misguided to regard the formal market economy as the only major world economy. Indeed, the informal economy is already (and has long been) the major source of livelihood for many people in the world, especially in developing countries, where much work is informal and self-organised. Moreover, there is a vast and burgeoning illegal and illicit economy, which is growing much faster than the formal economy (Hudson, 2014). So, it is not improbable that another form of economy could emerge alongside the formal, informal and illegal or illicit economies. If an economy of entrepreneurship and self-action does emerge from the scaling up of social innovation initiatives, it would most usefully be seen not as an alternative economy, but as a complementary economy.

Certainly, the mainstream economy is increasingly challenged because of the highly stressful, insecure and unsatisfying nature of much work (Schor, 1993; Sennett, 1998). Stress related to work load and job insecurity may lead people into an alternative or complementary economy and to become downshifters. Insights from positive psychology that classify materialism as a psychological disease are unlikely to cause governments to ban TV advertising but may lead to a part of society opting for less materialistic lifestyles. Environmental protection may then be able to piggyback on demands for autonomy and relatedness, and the creation of local schemes of production and consumption that offer greater independence from mainstream systems.

4.4.5 Financial regulation, alternative finance and de-financialisation

The 'financialisation' that has accompanied marketisation creates particular governance challenges in the context of transitions to sustainability. These need to be addressed using a variety of approaches and instruments in different transitions arenas.

In terms of mainstream markets, environmental improvement projects face fundamental obstacles concerning the availability of financial resources. Such projects are often long-term undertakings with high up-front costs and significant market uncertainties (Criscuolo and Menon, 2015). They are difficult to finance when investors are risk averse and expect short-term returns on investment. Environmental projects face the specific challenge that common resources and ecosystem services do not feature in orthodox accounting frameworks, with values assigned only to what is immediately in demand. Speculation — and current opportunities for speculative behaviours to manipulate and distort currency and equity markets — is also a barrier to more 'responsible' investment behaviours.

There exist a variety of ways to align investment incentives with environmental conservation goals. These include developing proper markets for natural capital and ecosystem services, using combined public-private financing programmes and instruments to support investment in green projects, and developing 'green' and 'responsible' investment funds. A potentially important innovation involves

extending the concept of offsetting by requiring project developers to compensate for any loss of natural capital and ecosystem services resulting from their project. This is being explored through the development of new governance principles, such as No Net Loss (NNL) (Tucker et al., 2013).

Another possible intervention is a tax on financial transactions to deter short-term speculation and to promote longer-term investments in 'real' projects. Although referred to as a 'Tobin tax' (after James Tobin, who suggested taxing all spot conversions of one currency into another), a financial transaction tax was actually suggested by Keynes in 1936 as a means to constrain speculation and reduce or eliminate 'noise' transactions. The technical feasibility of deploying such a tax is an unsettled issue, though several proponents suggest that this is made easier by ICT (information and communications technology) advances. The 2007 inquiry of the All-Party Parliamentary Group on Debt, Aid and Trade suggested that revenues from a financial transaction tax could be dedicated to achieving the Millennium Development Goals and to investment in climate change mitigation and adaptation (APPG, 2007). Alternatively, revenues could be used to insure the global tax payer against a future banking crisis (Barber and Parker, 2009).

New forms of financing and financial governance are also emerging in the complementary economy transition arena. An example is crowdfunding using internet platforms to raise capital for promising initiatives and projects (Vulkan et al., 2016). Performance assurance bonds are another important instrument that could bridge mainstream and complementary markets, by helping social innovation organisations take over some functions of service delivery now handled directly by central and local government or their agencies. These instruments could also overcome sectoral and departmental divisions in government and its agencies, and enable public money to be pooled and directed toward cross-cutting initiatives and projects that address more than one area of need (Weaver et al., 2016a).

4.5 Strengths and weaknesses

4.5.1 What are the strengths of the socio-economic transformations perspective?

The literature surveyed on socio-economic transformations in different ways brings out the role and nature of institutions, interests and social relations in relation to work, consumption, time activities, investments and government policies. Institutions, interests and social relations are viewed as an outcome of historical processes and as shaping factors of the future (reflecting the duality of structure and agency). More than in socio-technical transition studies and the work on socio-ecological transformations, attention in socio-economic studies is given to the role of capitalism as a structuring force for a type of need satisfaction, the attention afforded by industry and government to environmental protection, materialistic ways of living, growth imperatives (of firms, national economies and the global economy), and resource use of primary and secondary materials.

Capitalism comes in different forms (varieties of capitalism), which shows that it is not immutable but itself an outcome of social processes. Furthermore, markets are social constructs and can, in principle, be socially reconstructed to deliver better outcomes for society. In an open economy world, however, capitalism shapes the choices of national governments. The work of political economy and institutionalists is important for highlighting that government is not an external actor, but is best viewed as an institutional actor (or, even better, as an actor-based sub-system, i.e. a policy regime), whose choices are influenced by interests and ideologies, some of which are more privileged than others. The literature on socio-economic transformation views the capacity of government to steer society as constrained.

While accepting such limits, the literature also draws attention to many entrance points for government intervention and collective action relevant for sustainable development: ecological tax reform, environmental regulations, covenants, subsidies, property rights and legal forms of ownership and enterprise, reliance on self-management in the shadow of hierarchy, alternative measures of progress and wellbeing, acceptance of alternative currencies and basic income as a facilitator of an alternative economy and a freer, fairer and more democratic society.

The scope and nature of intervention depend heavily on context. Intervention can be 'orthodox' in the sense of being framed by the prevailing logics of markets and directed towards reducing social and environmental spill-over costs of markets and related processes or even harnessing these for environmental protection. They can also be communitarian, which offers scope for transitions focused on growing complementary economies and initiatives that open up possibilities for citizens to lead satisfying lives in less material ways. The two are not alternatives, but constitute potentially complementary and synergistic transitions.

A political economy view of capitalism helps to understand why green innovation is the favourite strategy of national authorities for greening the economy: it fits with the economic growth paradigm of jobs and wealth as the hegemonic view on the economy. A transformation perspective would be critical of solutionism in the form of market-based instruments, sustainability transition policies, and communisms and post-capitalism making the world a better place, by being mindful of barriers to sustainability policies and complex interaction effects.

The studies on downshifters show that wellbeing may be found in less materialistic ways for some people: for example, through leisure activities (e.g. piano playing, reading, walking) and living communally. As with peer-to-peer production, it is a bottom-up development that is not backed by economic interests and is dependent on cultural learning. The predominance of the cultural dimension means that it is not something that can be scaled up through government policies; it can be fostered, however, through instruments, such as basic income, and through local government action.

4.5.2 What are the weaknesses of the socio-economic transformations perspective?

A weakness of the socio-economic transformation perspective is that there is no specially devoted research tradition on this topic. Elements of socio-economic transformations (work, living, time activities, social protests, emancipation and the political economy of state policies) are studied by topic specialists (labour sociologists, sociologists of consumption, political philosophers, political scientists and political economists) operating in different fields. Scholarship is limited and fragmented, and sometimes overly deterministic (Patterson et al., 2015).

Above all, because the field is broad and covers many topics, the work within it is not structured around a framework that provides for recognising different kinds of socio-economic transitions in different transition sectors and arenas, or for showing how these might relate to and support each other. In particular, there is little appreciation of the potential importance of a complementary economy and of non-material sources of satisfaction, such as autonomy, inclusion, companionship and respect. Academically and politically, it is the mainstream economy that holds attention. This may indicate a need for transition in the perspectives on transition.

Despite its broad focus, the work on transformations to sustainability pays scarce attention to other transformations such as urbanisation into slums, which is occurring in large parts of Africa, Latin America and Asia; migration across the world (to escape poverty, war and the consequences of climate change); inequality and processes of exclusion (which are intensifying); calls for protection (in response to foreign competition and terrorism); and the rise of populists (especially in Europe and the United States).

The links with sustainability of various transformation processes begs further analysis, with the present chapter providing a crude first attempt at that.

4.6 Knowledge for socio-economic transformations

The issue of socio-economic transformation is mostly addressed in a partial way, through disciplinary research. A more integrated research approach is desirable. Patterson et al. (2015) note that, because trajectories of transformative change stem from co-evolutionary interactions, they cannot be viewed in a narrow disciplinary-bounded or deterministic way.

The interaction between the alternative economy and the regular economy and the role of government is a topic in need of further research. The scholarship on this area is small and limited. It seems that government efforts to engage everyone in paid work through coercive welfare policies and business-friendly policy incentives (such as lower tax rates for companies) are inadvertently doing a good deal of harm, for example by stimulating an illegal economy and promoting inequality and deprivation, while achieving little improvement in quality of life for all. Mazzucato and Perez (2014) offer useful advice in the form of a plea for a dual economy growth strategy in which advanced countries 're-specialise' in two types of activities: 'high quality or high complexity demand sectors (both in equipment and consumer goods or services) that cannot be based on low-cost labour, and domestic quality of life [activities] that cannot be offshored'. The former includes (mission-based) investment in technology opportunity areas (such as nanotechnology, biotechnology and energy storage) and the latter in 'the greening of the built environment, the sharing and the rental economies, the preventive and personalised health care services, other activities related to quality of life'.

In such a strategy, greening is achieved through new technology, for-benefit companies and domestic programmes aimed at making houses more energy-efficient, bans on waste disposal and the promotion of green forms of transport (e.g. bicycles, public transport). Cheap digital technologies and

unused resources (e.g. land, office space, unused tools and products, people's time that is not locked into paid work) offer opportunities for productive activity outside the formal economy. Co-maker spaces at the vicinity of waste depots may stimulate the upcycling of waste. Besides offering access to goods and services and possibilities for exercising competence, a complementary economy may also spread alternative cultural aspirations that are less material intensive.

A topic that attracts far less attention than it warrants is the significance of population growth. Although global human population growth rates have declined, the absolute growth numbers remain very large and have yet to peak. While limiting or reducing population sizes appears like an obvious means of managing future pressures on ecosystems, the link between demographic change and sustainable development is complex. Faced with the need to maintain economic expansion, welfare systems and intergenerational solidarity, most countries favour continued population growth. There is a need for more research into this important area.

Different forms of knowledge and ways of knowledge production are relevant for socio-economic transformation. Transdisciplinary research, advocated by Patterson et al. (2015) and Swilling (2016) is useful for making actors act on the basis of the knowledge that is generated. Through its focus on real-life problems and systems, and attention to values and interests, solution strategies may be defined that are mindful of (often conflicting or incongruent) interests, values and complex system interrelations. A key research priority here involves developing enhanced and more comprehensive transformative literacy in research and practice: 'the ability to read and utilise information about societal transformation processes, to accordingly interpret and get actively involved in these processes' (Schneidewind, 2013). In particular, the institutional and cultural dimensions of this literacy (e.g. social innovation) demand much more attention, given the dominant reductionist focus on the technological and economic dimensions.

More knowledge is also needed on the interplay (dialectics) of the three movements: the spread of values of autonomy, relatedness and purpose in the market economy and the spread of marketisation in the social economy realm. More research is also warranted on the question: what interventions in social welfare provision, company law and the science system can help transformative social innovation to expand and build a more social, inclusive and responsible economy? For example, what roles are there for basic income, mandatory community service, social impact bonds, vouchers for research and advice, and the creation of new legal frameworks for the commons and for-benefit companies?

5 Action-oriented perspectives on transitions and system innovation

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5.1 Introduction

Action-oriented perspectives focus on the role of formal and informal organisations and groups that are not part of national states and that actively seek to influence the transition to sustainability. This contrasts with the role of national governments in influencing transitions by means of central authority or the role of individuals via the market.

The Action Programme of the United Nations (UN) Earth Summit of 1992 (Agenda 21) identified such organisations and other social groups as 'critical' to its implementation. The term 'action oriented' is used in this review to signify the roles of actors that are distinct from either government policy or individual behaviour.

As well as targeting these particular types of organisation or group, the action-oriented perspective has two important consequences for the type of knowledge to be addressed in this review. The first is to recognise the role of knowledge that is articulated by these organisations themselves and to engage with problem framings that are often largely practice-based. The second is that a focus on 'action' often draws on formal social science knowledge, which addresses processes of change over time through agency and practice, rather than snapshot analysis of structure and performance (Poole et al., 2000). Such process approaches are expressed in the transitions and innovation literature, reflecting interpretive and relational approaches of a broadly sociological nature (Garud and Gehman, 2012).

Three principal types of organisation or group are explored in this review, all of which are highlighted in the UN commitment to 'strengthening major groups' (UNCED, 1992):

- Community-based non-governmental organisations (NGOs): These are informal and bottom-up organisations variously referred to as community groups, civil society, voluntary organisations or 'the third sector'. These actors are often concerned with general goals of community cohesion and resilience, but increasingly develop a role in the pursuit of environmental sustainability.

- City and regional local authorities: These represent either a spatial area or a level of governance at different scales and levels of cohesiveness, such as cities, towns, settlements, regions or agglomerations. They usually have a long tradition of action with respect to planning, economic development, environment, building and transport.

- Trade unions: These are organisations representing workers and trade or labour unions. Their main role concerns jobs, skills and wages, although they increasingly address sustainability issues

The first two types of organisation — community NGOs and city or regional authorities — engage in actions that are often location-specific, place-based initiatives at a variety of scales including the community or neighbourhood, town or city, and region or province. Among these, activities at the city scale are probably the most extensive and influential.

Trade unions and businesses are often less place based, and sometimes transnational in scope. Actions are therefore defined in some cases at a societal level and in others by a sectoral focus.

The action orientation of interest to this chapter is the explicit engagement of these different groups of stakeholders with the concepts of sustainability transitions and system innovation, linked to the relatively new policy concept of the transition to a low-carbon society or a green economy. The focus is on particular domains of action and categories of social actor. The knowledge fields associated with this action-oriented perspective are often hybrid in nature, with practice-based knowledge and academic studies intertwined. The fields of interest are those where there is clear evidence of significant recent attention to innovation and transitions.

5.2 Conceptual background

5.2.1 Polycentric systems

The notion of 'polycentric systems' is a major conceptual influence affirming the importance of the distributed action of organisations and groups on global environmental problems (Ostrom, 2010b). This rejects the conventional theory of collective action, which requires top-down enforcement of social rules on self-interested actors. Instead it argues that empirically there are many examples of bottom-up cooperative actions. This suggests a much more positive role for a polycentric system of actors at multiple levels and scales to enable collective actions addressing global environmental problems.

Three particular routes are envisaged for action-led approaches to influencing global problems. The first is the 'cumulative' consequence of many small-scale local actions. The second is the favouring of 'cooperative' modes of action 'using local knowledge and learning from others who are also engaged in trial-and-error learning processes' (Ostrom, 2010b). Such systems benefit from 'mechanisms for mutual monitoring, learning, and adaptation of better strategies over time', thereby enhancing 'innovation, learning, adaptation, trustworthiness, levels of cooperation of participants' (Ostrom, 2010b). Finally, recognising that some top-down action is needed to address free-riding, the third role of polycentric actions is in securing 'consent' for such top-down actions. These cumulative, cooperative and consensual processes are seen as the great strengths of polycentric systems.

The fundamental re-conceptualisation of social action as a 'polycentric system' took place in parallel with a broader shift in global policy practice on climate change to a bottom-up rather than a top-down approach arising from the Copenhagen Climate Change Conference in December 2009 (COP 15). This approach has been described as a 'building blocks' alternative to a 'global deal' model (Falkner et al., 2010). Yet the proponents of this alternative approach are anxious to distinguish it from 'a thoroughly "bottom-up" model of climate governance which relies solely on decentralised national and sub-national climate measures'. Instead it 'combines the long-term objective of a global climate architecture with a dose of political realism in the process of creating this architecture'. It thus retains the key role of international agreements between governments on the understanding that 'preventing a collapse into a decentralised, purely bottom-up, approach is of critical importance'.

Since the early 1990s, the global sustainability policy arena has been characterised by a coevolution of policy discourses and academic concepts, affirming the importance of actions pursued by diverse non-state actors. Although accompanied by debates over the primacy of top-down or bottom-up dynamics, there has been a convergence over the importance of actions pursed by these organisations and groups. This has been expressed most recently in the Paris Agreement on climate change of December 2016 (UNFCCC, 2016b).

The Paris Agreement includes a specific section that welcomes the efforts of 'stakeholders' who are not national governments 'to address and respond to climate change, including those of civil society, the private sector, financial institutions, cities and other subnational authorities' (para. 133). It also agrees to 'promote international cooperation in order to mobilize stronger and more ambitious climate action' by this diverse mixture of stakeholders; welcomes the efforts of these stakeholders 'to scale up their climate actions'; and encourages 'the registration of those actions in the Non-State Actor Zone for Climate Action platform' (para. 117). The stakeholders are invited 'to scale up their efforts' and to 'demonstrate' them (para. 134) through this platform (http://climateaction.unfccc.int).

5.2.2 Transition reframing

The new post-Paris focus on wider stakeholders expresses a longer-term process of policy change. The emergence of transitions policy was presaged by academic research in science, technology and innovation studies along with reviews principally by climate scientists through the Intergovernmental Panel on Climate Change (IPCC). However, the passage point into the active policy domain was expressed by the Stern review of 2006, which identifies the 'transition to a low carbon economy' as an overarching principle (Stern, 2006). It has subsequently been translated into a variety of policy measures on energy transition in Germany and the transition to a green economy in the United Kingdom.

The concept of transitions represents a different action framing for both innovation policy and sustainability policy. It broadens the scope of innovation away from its traditional technology-driven product and process focus and broadens the scope of sustainability to embrace wider economic and social transformation. However, its use internationally for reframing discussions on sustainability and climate change is still quite variable. For example the transitions concept receives attention in the IPCC Fifth Assessment Report on Mitigation of Climate Change (IPCC, 2014a) but is hardly mentioned in the Paris Agreement. It is a consistent and central concept in the EU's 7th Environment Action Programme (EU, 2013b),

yet plays a more marginal role in the United Nations Conference on Sustainable Development (Rio+20) statement on 'The future we want' (UN, 2012).

In addition to uneven use, the concept of transitions is linked to a diverse mixture of sustainability narratives. Academic literature and policy documents cite the need for a transition to sustainable development, a sustainable society, a low-carbon economy, a green economy, a resource-efficient economy and a circular economy (Speth, 1992; Grin et al., 2010b; UNEP, 2011c; EC, 2016a, 2016b). Transitions are related to different types of system change, ranging through socio-technical systems, socio-ecological systems, the food-energy-water nexus, and patterns of sustainable consumption and production.

This wide if uneven usage does suggest that it is a framing that offers flexibility and pervasiveness. Yet it is important to recognise that it is new and distinctive in addressing elements that were not given such status in earlier environmental and sustainability discourses.

As summarised by Steward (2012), the transitions discourse is distinctive in being:

- challenge led: using 'backcasting' of long-term goals (e.g. emission reductions) to generate near-term targets;
- focused on systemic change: requiring the reconfiguration of meso-level systems of many social and material elements;
- transformative in nature: involving radical change to existing modes of economic and social activity.

It is particularly interesting to consider how the new 'collective action frame' of transitions is being built and used by social actors in 'framing processes', that is, in 'the generation, diffusion, and functionality of mobilizing and counter-mobilizing ideas and meanings' (Benford and Snow, 2000). The next section therefore provides examples of ways in which non-state actors and groups are engaging and using the notion of transitions and then explores how these activities are interpreted by academic analysts.

5.2.3 Action theory

What has been called the 'action turn' in social science (Reason and Torbert, 2001) expresses a complex mix of different strands. One is a tradition of action research, which espouses an interactive engagement between analyst and actor through a hybrid domain of research and practice. More broadly it also signifies a variety of conceptual approaches that emphasise interaction, networking, persuasion, enrolment and enactment to explain change and innovation. The focus is therefore on action and actors rather than the role of general social and economic factors.

Action research methods often follow the process of change over time and are qualitative rather than quantitative. These span a wide variety of approaches, including actor-network theory ('follow the actors'), practice theory and relational sociology. These contrast strongly with the positivist traditions in much sustainability research.

This review seeks to identify these action-oriented strands of knowledge engaged with transitions and to develop some patterns and typologies to help situate them more clearly from the viewpoints of research and practice. It does not seek to overcome the eclecticism in this area of social science but to help identify and interpret it more meaningfully.

5.3 Understanding transitions — case studies and academic analysis

5.3.1 Community

This section discusses community approaches to transitions to a low-carbon economy or towards more specific sustainability objectives. The focus of the actor-led initiatives discussed here is on community-led initiatives that are implemented within a specific (most commonly geographic) community. As such, the section focuses on community organisations as the primary stakeholders or social actors promoting and implementing the approach.

To understand the shared elements of large numbers of specific community initiatives, a key focus here will be on the umbrella organisations that network community-level organisations, which are themselves aiming to achieve systemic and transformative change. These organisations typically have a location and a small staff but operate primarily through their virtual presence, which articulates the model of community action and provides resources. Of particular interest is also the articulation of the network model employed to recruit and retain community groups, and, within this, their approach to promoting social learning. These dimensions provide a way to explore the potential for 'scaling up' community initiatives.

Examples of community-led initiatives

Transition Network (www.transitionnetwork.org)

The dominant community-led movement in relation to climate change transitions is the 'transition towns' movement or Transition Network (TN). Active since 2007, by 2014 it claimed 1 120 registered transition initiatives in 43 countries. There are 20 national hubs outside the UK (where it originated), mostly in Europe. Its use of the term 'transition' signals a clear focus on a change process with low-carbon objectives (as opposed to approaches that focus on a distinctive outcome).

The TN has emerged from what was initially called the transition towns movement, which had a very clear methodology for developing a locally based transition. Until recently it was a requirement to follow this approach to become a registered part of the network. Much of the academic critique below addresses this approach, which is still present in the training provided to groups by TN. However, the network is now more open and the approach less prescriptive.

The TN retains core values and principles. The first of these is to 'respect resource limits and create resilience' (TN, 2017a). This includes a commitment to reduce energy use and to use other resources sparingly and, in this and other ways, to create more resilient communities with a higher level of self-sufficiency, which are better able to withstand climate change. Core beliefs are that the era of cheap, plentiful fossil fuels is over ('peak oil') and that this requires a reduction in energy use. This is facilitated by the encouragement to produce 'energy descent action plans'.

This approach contrasts with the contention that oil and other fossil fuels can be replaced by other energy sources. As such the TN vision is of a different way of living that recognises resource limits. This vision is based on permaculture: originally an approach to agriculture based on natural systems whereby inputs, waste and intervention are reduced to a minimum, but increasingly drawing on wider system thinking to apply to society more broadly.

A core TN concept is that of positive visioning and creativity (TN, 2017a). Rather than being against things, participants are encouraged to imagine the type of society that they would like to see in the future and then work back to how they can create this. This is not an open-ended process given the stress on resource limits, resilience and social goals of inclusivity and social justice. Common themes are reduced consumption and learning from 'elders' about reusing resources; resilience from 're-localising' food; and establishing other resource networks including setting up new enterprises and using local currencies (TN, 2016).

Nevertheless, the TN increasingly stresses the role of local initiatives in defining their own path. Principles include subsidiarity and being part of an experimental learning network that freely shares ideas and power (TN, 2017a). The TN itself does have a clear role in encouraging the growth (or at least the resilience) of the model. It describes its role as holding the transition 'source code' and 'catalysing and supporting the spread of transition globally' (TN, 2017b). This model pays a lot of attention to community development and stresses the risks of becoming caught up in individual projects. There is an emphasis on celebrating successes and acknowledging failures, although the TN has only recently promoted monitoring and evaluation techniques. As a result of collaborative academic research, a guide is now available for groups (Hobson et al., 2016).

The underlying TN model is holistic and focused on carbon reduction. It used to appear rather uniform and prescriptive, but a recent publication (Hopkins, 2015) produced as part of the TN's contribution to the 2015 United Nations climate change conference (COP 21) negotiations features a diverse range of projects including seed exchanges, community cafes using food that would otherwise go to waste, a repair cafe, community housing and local currencies. The transition model envisages sub-groups working on particular projects, and these examples perhaps give a better flavour of the activities in a particular transition town than is suggested by the core model. This approach is now reflected more fully on the TN website.

Global Ecovillage Network (www.gen.ecovillage.org)

The Global Ecovillage Network (GEN) appears to have a similar concept of sustainability as that held by the TN. Indeed, the GEN website claims 'transition town initiatives' as part of its network. The similarities are the holistic approach to sustainability, reduced energy use, and local production and consumption. However, the networking model, target audience and scaling approaches are distinctive.

The organisation dates from 1991 (Joubert and Dregger, 2015) but has experienced different levels of types of activity and the current leadership dates from 2008. GEN has its origins in self-organising, 'utopian' communities such as Findhorn in Scotland. Many have a distinct spiritual dimension. Ecovillages are defined as 'intentional or traditional communities that aim to regenerate social and natural environments' with a 'sustainable development model that is adapted to local contexts. Ecovillages are consciously designed

through locally owned participatory processes' (Joubert and Dregger, 2015). As such, the model of transition includes a strong element of creating new communities either from scratch or from 'traditional' villages.

There is a representation from developing parts of the world including, for example, Sarvodaya, a network of 2 000 active sustainable villages in Sri Lanka. Increased local sustainability is combined with trading arrangements, which in some cases are significant.

The networking model is less centralised or prescriptive than the TN. However, it does have a large-scale educational programme with a goal to educate at least 10 000 people annually by 2020 in the principles of sustainability and ecovillage design (GEN, 2015). These courses are often held in an existing ecovillage location promoting a 'living and learning' approach. The curriculum is made publicly available for those who wish to use it independently. GEN has also been active in promoting ecovillage ideas at the UN level and since 2000, has held a consultative status with the UN Economic and Social Council. GEN holds events at UN climate change conferences to promote its approach (see http://gen.ecovillage.org/en/cop22).

GEN is currently developing transition strategies, which seek to strike a balance between promoting a particular approach and local autonomy in scaling up the numbers of sustainable communities it works with directly. This will be based on increased partnerships with 'governments, NGOs, and donors to implement policies and solutions at local, regional, and international levels' (http://gen.ecovillage.org/en/page/ecovillage-transition-strategies). Much of this seems to focus on policy changes in developing countries, for example a national strategy in Senegal to transition 14 000 traditional villages to ecovillages. GEN says that its 'big solution' is empowering the millions of small solutions.

Community Power — for people's ownership of renewable energy (www.communitypower.eu/en/publications.html)

Both the TN and GEN use holistic approaches to the multiple dimensions of sustainability. In contrast, other community approaches to low-carbon living, while still systemic, are more focused on a specific 'end use'. The most relevant and pervasive example is the community energy movement. The example chosen here is Community Power, which aims to support and promote community-owned renewable energy projects, but sees this as including the need to inform policymakers, promote legislative change and encourage the development of novel finance models.

The project is run by Friends of the Earth Europe (and involves a number of national Friends of the Earth hubs as partners). It received co-funding from the Intelligent Energy Europe Programme of the EU. The project has produced recommendations, and case studies are available from its website, which are intended to raise awareness of community initiatives. More broadly, and a key reason for inclusion here, the project argues that community ownership of renewable energy initiatives produces wider benefits. In addition to building public support for renewable energy and providing investment, these include creating 'stronger, healthier communities' through working together on a common goal, and promoting efficient use of energy. The wider goals of influencing legislation, regulation and finance models raises issues about the extent to which a radical transition towards renewable energy and its efficient consumption can be located solely at community level.

Open Food Network (www.openfoodnetwork.org) and **The Food Assembly** (www.thefoodassembly.com)

Increased local production of food is an element of almost all broad community initiatives as represented by the TN or GEN. In some cases, this has involved extensive attempts to produce a wide range of foodstuffs. Other initiatives, such as community orchards, have been more symbolic, at least in terms of its contribution to self-sufficiency. In any case, accounting for the sustainability of food has proved a complex issue for a range of reasons. These include the challenges of balancing food miles against inputs to farming in different climates, and accounting for different modes of transport. Looking at the issue from a wider social perspective, there are also complex considerations of the role of cash crops in the economies of developing countries and the disconnect between the diets of most Western people and local seasonal production.

The Open Food Network (OFN) and The Food Assembly are two examples of attempts to support community-level hubs between local consumers and producers. They work by providing specialised software that supports the creation of an online market, allowing local volunteers or social enterprises to manage orders and deliveries (or pick-up locations).

The OFN operates in Australia and the United Kingdom (with developing organisations in Norway, South Africa and other locations). OFN provides the software to allow trading. A UK example is the Stroudco Food Hub (http://www.stroudco.org.uk/how-it-works/).

The Food Assembly operates in a similar way with supported organisations in the United Kingdom and

across northern Europe. As well as allowing residents to buy food produced locally, these systems support the sustainability of local producers by allowing them to market directly to consumers without the costs of direct outlets or having to sell at a much reduced price to local retailers.

Academic analysis of community-led transition initiatives

Community initiatives and systemic change

For many community activists the significance of acting at the local level (often vaguely specified) is largely an article of faith. This is in line with the widely known, if disputed, Margaret Mead quote 'Never doubt that a small group of thoughtful, committed citizens can change the world. Indeed, it's the only thing that ever has.' In support of their belief that this is the correct level, community activists point to examples of changed communities. Such case studies 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.

This is, at least in part, an argument about scaling up: will the transformation of individual communities simply cascade until the whole society is transformed or are there barriers that need to be addressed at a different level or in a different way? This argument is explored below.

Even those sympathetic to the community change approach raise questions about the scale that is most appropriate to such attempts (Aiken, 2015). The community development model behind the original transitions network stressed that change comes when people fully understand the issues, own the problem and have group structures and dynamics to allow a meaningful programme of change to be developed. In the original model this involved a very small core group, at least in the early stages. However, if the goal is some form of place-based self-sufficiency, then this implies a much larger group of people.

Although rarely set out in these terms, these two dimensions of scale are arguably pulling in opposing directions. More traditional community-based environmental activism, such as Friends of the Earth, have worked in a very different way, with locally based groups campaigning on issues often beyond their local area such as reducing air travel. This can be illustrated by contrasting Friends of the Earth's web page on climate change actions (FOE, 2017) with the TN's website and identified actions.

It is not only the scope of activities. The traditional TN model started with the creation of a strong and resilient community that understands the problems and the way they can be addressed. Only at stage seven of the 12-step model are groups advised to 'develop visible practical manifestations of the project'. Critics (Smith, 2011) argue that this approach inhibits wide engagement and, as such, contributes to the lack of diversity of members of transition town organisations. Surveys have shown that members are overwhelmingly highly educated and not representative of the demographics of their geographic community. This raises doubts about whether such an approach is really capable of transforming society at large.

Critics further point to the elision between the usually small community group promoting the change and the community they are seeking to change: exemplified by the name of projects that are part of the TN, for example 'Transition Cardiff' (Aiken, 2012). This can be particularly problematic when it comes to the final stage of the original model, the 'energy descent plan', which needs to involve the whole community. It raises questions about for whom, and by whom, the plan is being made (Smith, 2011).

The stress on building up a strong coherent organisation around TN principles has also been a source of tension where transition organisations have tried to incorporate existing environmental initiatives within their framework of change (Connors and McDonald, 2011). Arguably these criticisms are less problematic for 'intentional' communities, which provided the original impetus for the GEN and were formed around the principles of a sustainable community.

Social practice perspectives on operating locally

For the other initiatives described above, a rather different argument can be made about the importance of working at the community level. The issue is that although an individual may be fully committed to buying locally sourced food (or adopting some other aspect of sustainable living) it is not possible to do this without a community of producers and, arguably, shared knowledge of cooking techniques and recipes. From the academic literature this fits best with the 'social practice' perspective**.** This perspective frames practices as being not just what people do (performances) but also configurations of materials, competencies and meanings (collectively known as entities) that come together, persist or dissolve within specific places and times. Understood in this way (Pink, 2012; Shove et al., 2012), practices recruit individual 'carriers', rather than the other way around.

The social practice approach provides a powerful theoretical defence of the significance of community-level initiatives since it roots change in groups of people rather than individuals. The distinctive contribution that community-led initiatives make to the spread of new practices (and through this potentially to sustainability transitions) is perhaps best captured by the social learning communities of practice literature (Lave and Wenger, 1991). This gives a different view of the 'scaling up' that can be achieved by, for example, a TN group operating within an existing community, such as a town. Rather than having to persuade every individual to make different choices in their consumption or behaviour patterns, the group's activity can bring into place new materials, competences and meanings that can make new social practices more visible, viable and liable to be adopted. According to this model, scaling up is much more contingent and emergent, and occurs in a distinctive way in places and over time. This is in contrast to a criticism of the original TN model that claimed that it was overly prescriptive and culturally blind (Connors and McDonald, 2011).

More broadly, a 'practice perspective suggests modesty on the part of policy as regards influencing social change' but it also shows 'that social change happens all the time' and that it is possible to intervene by 'guiding the direction of such change, and being sensitive to the inadvertent effects of policy which might lock-in or even encourage resource-intensive ways of life' (Spurling et al., 2013).

The social practice model has an additional important input to make to debates about scale. One significant development claimed by social practice theorists is recognition of the importance of materiality ('things') in contrast to earlier social and cultural theorists. For Shove et al. (2012), this category includes 'objects, infrastructures, tools, hardware and the body itself'. If new sustainability practices are identified in relation to, for example, activities associated with cooking, heating homes or travel, it would seem likely that some of the 'material' involved will operate with different levels of effectiveness at different scales. For example, target consumers of locally produced food expect to be able buy it very close to where they live (or even have it delivered to their door). However, particularly in urban settings, local food projects have to source from a wide area to produce a sufficient range of goods. This will involve transport, which may undermine the sustainability of the product. Locally produced food in particular climates may further only be viable if they have high energy inputs such as heated greenhouses. In the case of local energy projects, combined heat and power projects are viable in dense urban settings but not in more rural settings. Many people live easily without a car in urban areas but to do so in a rural area is a much greater challenge.

Does changing the community change society?

Returning to the argument about whether society can be changed simply by changes within individual communities, there are criticisms from wider political commentators. At the broadest level critics have argued that to claim change needs to be made at the 'local' level is to wrongly locate the source of the problem of an unsustainable society (Amin, 2005; Aiken, 2015). The root cause of unsustainability is the capitalist economy, based on global businesses requiring ever-expanding markets for consumption of goods, which in turn require the extraction and waste of resources and energy. Correspondingly, this is the level at which change needs to occur.

This may be something of a 'straw man' criticism. The community initiatives discussed above are not unaware, or dismissive, of the power of consumer capitalism. Indeed, part of the work of initiatives is to address it directly, believing that the experience and example of living well differently will contribute to change in the political economy. The environmental movement has always encompassed a mixture of social movement organisations addressing business and government activities, and focused on local community change. Many organisations encourage both: some focus on macro-level change (including social movements and green political parties); others, including the TN, argue that the focus should be on the changes within the community rather than engaging in wider 'political' struggles.

Chatterton and Cutler (2008) make a clear argument for the need to do both. They argue from the perspective of a 'critical friend' of the Transition Town Network (as it was then named). They find the notion that an overall change in society will occur from a snowballing of community initiatives implausible. Large corporations will not give up profitable enterprises without a struggle and a degree of state or indeed international pressure will be needed to change all in a society where many will remain indifferent or wedded to current practices. They celebrate the local initiatives but argue that these must not remain solely activities within the community but also involve, for example, campaigns against continuing fossil fuel extraction and power generation.

Community initiatives and government policy

The risk of community organisations over-estimating their ability to change society through location-specific

initiatives is sometimes seen as being echoed by governments that engage with community actors as a convenient route to promote pro-environmental behaviours and manufacture consent for state-led sustainability policies (Aiken, 2015). This use of the 'local' and 'community' is said to be a way of delegating agency and responsibility for global events to individuals on the ground. Local community groups are used to deliver state initiatives, such as the UK's Green Deal, at a low cost and through community networks, or they are co-opted into accepting renewable energy through grants for local facilities. At the same time, wider environmental campaigns and political actors are marginalised.

The alternative good life

Spurling et al. (2013) argue that the 'innovating technology' policy response to climate change is grounded in a vision of the future as very similar to the present. It reflects a belief that sustainability can be achieved through lower inputs and more efficient technologies. An obvious example is continuing with a transport system dominated by the private car but powered by electricity (or possibly another fuel) generated from renewable resources rather than fossil fuels.

Of the actor initiatives discussed in this section the majority clearly adopt a different approach, stressing the need to reduce consumption. Community initiatives do embrace some aspects of the innovation strategy — for example better building design and insulation of existing buildings — but they also explicitly engage with the need for consumption patterns to change.

Mainstream politicians and policymakers are wary of explicitly advocating reduced consumption because it may be perceived as telling people that they need to accept a 'worse' lifestyle than they have currently. However, this is not the position of community activists, who stress that they are advocating an alternative 'good life'. This position is also reflected in academic literature, such as Soper (2008). Some academic studies suggest that a 'living differently' approach could be part of sustainability transitions. Examples include a study of the Japanese government's 'Cool Biz' campaign to reduce air conditioning (Shove et al., 2012) and Jamie Oliver's food waste campaign to promote 'ugly' vegetables (Oliver, 2016).

The social practice perspective criticises the 'innovating technology' approach for assuming that technical change can be considered in isolation from social practices. In fact, Shove and Southerton argue that adoption and use patterns of new technologies cannot be understood separately from the changing competences and meanings that also make up current social practices. Social practices are changing all the time, as illustrated, for example, by the changing use of domestic freezers over the last 50 years (Shove and Southerton, 2000). Rather than just substituting one technology for another, they argue, achieving sustainability requires that sets of relationships between technologies and everyday practices be reconfigured to achieve more sustainable practices.

Beyond individual behaviour

Influencing consumer choice and changing individual behaviour towards more sustainable options has been the dominant policy approach for public sustainability campaigns (Shove, 2010). In the United Kingdom it has been influential in the way the state has funded and worked with community-level initiatives. The approach draws on extensive academic literature on innovation and diffusion, which looks at the way that rates and patterns of adoption are influenced by opinion formers and their networks (Rogers, 1962).

Recent UK funding schemes have identified 'community champions' who are thought to be able to influence others, particularly those that the state and business find hard to reach. Evaluation studies have given some credence to this approach (Watson et al., 2004). Community ventures can also act as demonstration models for the diffusion of sustainability innovations, such as sustainable building materials or renewable energy (Steward et al., 2010). Academic work from a social psychology perspective has also developed accounts of how individual behaviour can be influenced by peer pressure or 'choice editing' (Jackson, 2005b; Darnton, 2008; Thaler and Sunstein, 2008). The latter work helps to address the limitations of the 'rational choice' explanations of individual behaviour, which dominated early psychological theories.

As with the innovative technology strand, social practice theorists are critical of such responses since they do not fully take account of the wider context in which consumer choice and individual behaviour are exercised (Shove, 2010; Spurling et al., 2013). Yet it is not always easy to apply the academic distinction between social practice and behaviour change approaches to case studies. Since the dominant policy approach is based on the behaviour change approach, funding opportunities and evaluations often assess community initiatives from this perspective. However, it is clear that the community activities described do display appreciation of the issues raised by social practice academics.

To take the food networks as an example, the creation of new networks of producers and consumers recognises that it is very difficult for an individual to purchase locally, sustainably grown food from conventional outlets and for such producers to make a viable living. In some cases, these initiatives also include recipe ideas — again showing that changing eating practices also requires changed skills in thinking about what makes a balanced and appetising meal as well as how to produce it. Similarly, those encouraging the increased use of cycling as a transport mode have not only promoted it as a desirable behaviour change but also provided training on cycling in traffic, bicycle maintenance places and training, secure storage, safe routes and showers at transport hubs or workplaces (Shove et al., 2012).

Community initiatives and the multi-level perspective on sustainability transitions

Disrupting unsustainable regimes

As with social practice theorists, analysts of sustainability transitions from the multi-level perspective (MLP) (see Section 3.3 above) are critical both of the innovation-push model and of social psychological attempts to explain and influence choice and behaviour.

The MLP identifies three levels at which change can occur: landscape, regime and niche. Most academic writing on community-level sustainability activities from a multi-level transitions perspective have focused on the niche level. This is discussed more fully below. However, Smith (2012) reflects more widely on the influence of civil society energy initiatives at both the regime and the landscape levels. At the broadest level, he argues that the development of social and cultural values of environmentalism; awareness of, and concern about, climate change; and the articulation of visions of the future, all impact on the 'landscape' (Figure 5.1).

Civil society action is particularly important because of its ability to unsettle, disrupt and challenge incumbent regimes. Such action can include consumer boycotts of unsustainable products; protests, direct action and lobbying against particular developments such as the expansion of coal-fired power stations, opencast mining or fracking; developing or pressing for better environment standards or regulation; and shaping and articulating societal understandings of particular regimes as unsustainable and promoting visions of alternatives. Social movement theories have explored how such action can be influential in shaping public policy and the programmes of political parties. Smith (2012) argues that bringing social movement analysis within the MLP framework could be illuminating for an analysis of the way regimes are unsettled. This is not of course to suggest that all civil society activity promotes sustainability transitions. One could equally point to groups protesting against wind farms as having a significant role in supporting the existing energy regime.

This discussion of regime disruption also links to the dispute between those arguing for local action and those advocating wider political engagement. Although these are often seen as being in opposition, at the heart of the MLP approach is an understanding of the relationship between these levels. Unsettling the current energy regime can provide space for niche-level initiatives around community energy generation to be assessed more seriously or supported more effectively. Moreover, such community-level initiatives enable challenges to the regime to gain strength by demonstrating the emergence of viable alternatives.

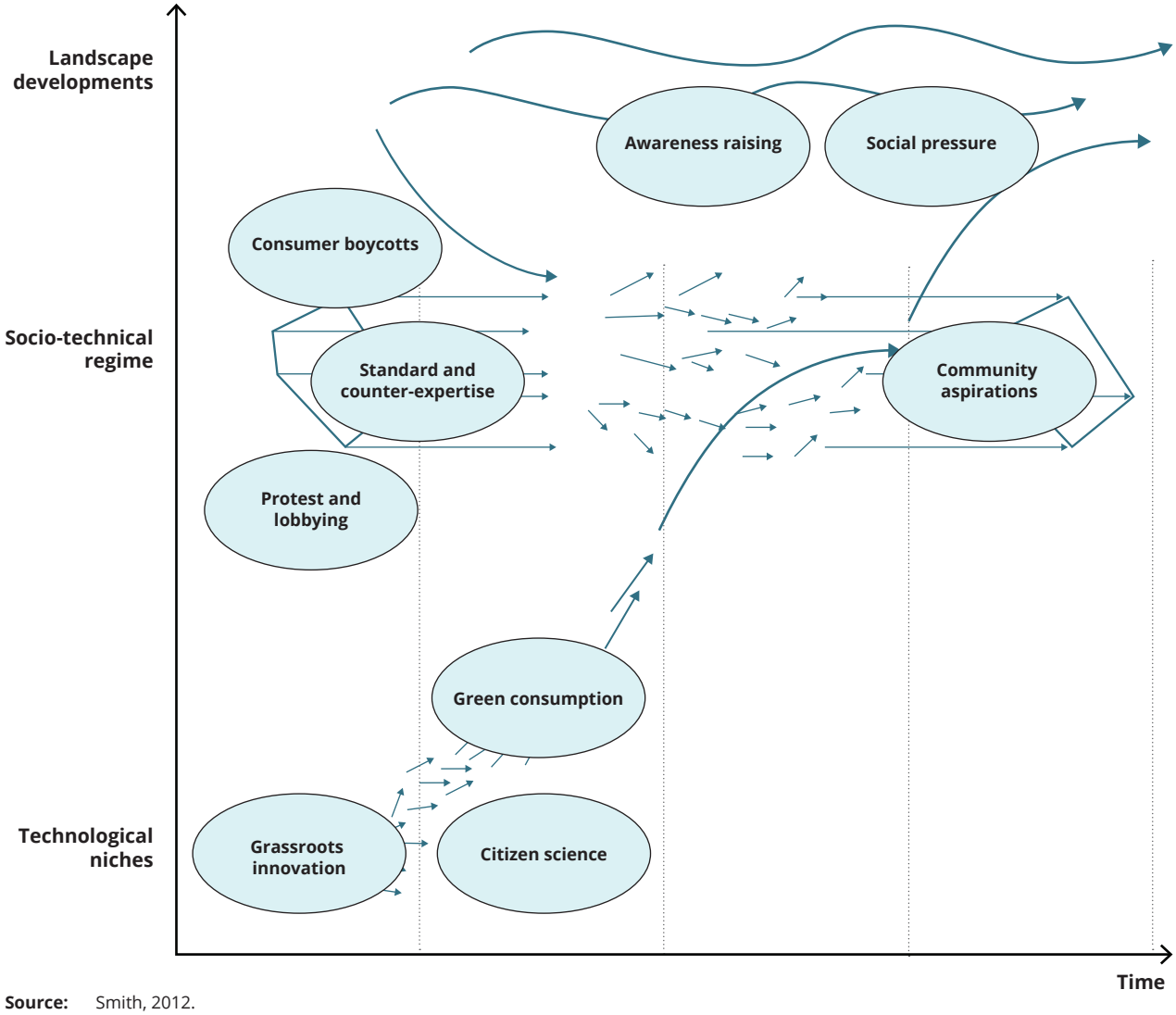
Community actions supporting niche innovation

The greatest academic focus from the MLP on community activities has been on their role as a source of niche innovations. The creation of opportunities for innovations that can contribute to the development of an alternative regime is thought to occur in protected 'spaces' within a supportive framework (Kemp et al., 1998). Once they have been sufficiently developed and tested in the niche, it is argued that such alternative socio-technical systems can 'in whole, or part, replace, transform or modify the dominant system'.

Seyfang and Smith (2007) have explored the community sector's potential to provide the context within which an alternative to the current carbon-based regime could flourish . Their work discusses 'civil society arenas' within which networks of activists and organisations generate 'novel bottom-up solutions for sustainable development; solutions that respond to the local situation and the interests and values of the communities involved', which they characterise as 'grassroots innovations'.

The values of the community organisations (particularly a focus on quality of life and self-reliance) and the social economy more broadly (particularly re-investment and volunteer input) are seen as providing a context within which innovations involving higher costs or inputs will be tolerated. According to Seyfang and Smith (2007), green niches are 'sustainability experiments in society in which participation is widespread and the focus is on social learning.' In particular such experiments are able to provide a demonstration that an alternative way of living is possible. The claim is not that all such

Figure 5.1 **Mapping civil society activity in sustainable electricity transitions**



Source: Smith, 2012.

innovations will be significant or successful — indeed innovative diversity is seen as a necessary aspect of a niche. Nor is it necessary for groups to see what they are doing in these terms or to have any explicit intention to transfer their ideas and practices to the mainstream economy.

To fully develop an alternative to the dominant regime, niche innovations need to link producers and consumers in comprehensive new systems of provisions (Harris and Albury, 2009). Even without such systems completely displacing existing ones (for example people buying some food from conventional outlets as well as from new food networks), new networks can provide opportunities for learning and reflection on different approaches. However, it is implicit in this approach that the innovations under discussion are broadly based and integrated.

The extent to which community-based initiatives can be understood as providing a niche space for developing innovations and their impact on dominant socio-technical regimes have been explored in relation to organic food (Smith, 2006; Seyfang and Smith, 2007) and sustainable housing (Smith, 2007; Seyfang, 2008). These accounts and those from the wider innovation literature suggest that there are some tensions here. Innovations compatible with the existing regime are likely to find it easier to upscale but may, as a result, have less power to transform. In any case they will need to enrol a range of well resourced actors to make the transfer to the mainstream. The process can be helped if the innovation addresses an identified problem in the regime — but again this requires effective engagement with policy and other actors.

In their detailed investigations of these issues in relation to food systems and sustainable housing, Seyfang and Smith explore a range of tensions. These include tensions between the skills needed to develop the niche innovations and those required to 'mainstream' them, and between achieving some transfer into the mainstream economy and preserving the characteristics that make it an alternative. Smith (2012) develops these arguments in relation to community energy initiatives and notes that the processes by which grassroots innovations transfer from the niche to the regime level remain underdeveloped theoretically and empirically. He notes that diversity is an inherent characteristic of civil society and cautions against superimposing some coherent, manageable process on to it. However, he also suggests that there is scope for exploring the role that social movements (and theories about them) could play in understanding how 'community energy niches attain identities and interests necessary for them to influence changes'.

There are important links, as well as differences, between social practice perspectives and the MLP in their treatment of sustainability transitions. Both reject the dominant policy perspectives of transitions occurring primarily through technological innovation or individual behaviour change. Instead, they both root transitions in a complex web of socio-technical change with institutions and networks that need to be reconfigured for change to occur. Yet they also have important differences, particularly relating to levels of analysis and the extent to which transitions can be 'managed'. While these differences have led some to assert the claims of one over the other (Shove and Walker, 2007), there have also been attempts to see whether or not it is possible for these two approaches to supplement each other with each addressing some of the issues that are less well tackled by the other.

Hargreaves et al. (2011) pursue this with a particular focus on civil society actors. They argue that these actors are particularly under-explored in the MLP (in comparison with market and state actors) because their activities 'attempt to dismantle and remake existing concepts of what is normal' as well as generating novel ways of doing things. In relation to this they point to limitations in the MLP's focus on single regimes. In contrast, they argue that social practice theory is much better able to conceptualise the complexity of everyday life where, for example, changes in cooking practices may impact on the regimes of energy, transport, water and food. In contrast, they suggest that the MLP is better than social practice approaches in explaining how novelty emerges and change happens. Overall they suggest considering social practice approaches alongside the MLP to incorporate both the horizontal 'dynamics of normality' and the vertical 'dynamics of novelty'.

5.3.2 Cities and regions

The past two decades have seen a proliferation of sustainability-oriented actions by cities and regions. The review of actors focuses on the major international networks that have been established to represent these diverse actors. This both makes the task a manageable one and also addresses the viewpoints of organisations and networks that have an expressed intention to enable a process of wider change.

The rise of international networks of cities addressing sustainability and climate change has been a prominent new development that has been interpreted as representing a new mode of transnational network governance (Bulkeley and Castán Broto, 2013). There are many city networks and initiatives that promote urban transition, but this analysis focuses on the major international initiative of the Global Covenant of Mayors on Energy and Climate Change and its precursors. The academic articles on cities sometimes address these networks but more often present case studies of one or several places. The discussion of academic analysis of city-led initiatives below includes articles of both types that explicitly address the notion of transitions.

Examples of city-led initiatives

Global Covenant of Mayors for Energy and Climate Change

The launch of the Global Covenant of Mayors for Energy and Climate Change in 2016 was the culmination of more than 25 years of initiatives to create transnational networks of city and regional authorities to promote sustainability. Involving more than 7 100 cities from 119 countries with a total population of 600 million, its mission is 'to assist cities and local governments in their transition to a low-carbon economy'. It is 'an international coalition of local and regional authorities with a shared long-term vision of promoting and supporting voluntary action to combat climate change and move to a low-carbon society'. The initiative establishes a 'central platform that brings together relevant data on cities' energy and climate actions' and measures their progress towards meeting climate change reduction goals (GCOM, 2016b).

The Global Covenant of Mayors is a fusion of the previously existing Compact of Mayors and the EU Covenant of Mayors. The Compact of Mayors was

created in 2014 when the oldest and most extensive international city network, International Council for Local Environmental Initiatives (ICLEI) (founded in 1990) joined forces with the newer C40 Climate Leadership Group (established in 2007). In cooperation with the UN it launched an open network for city participation, combining ICLEI's inclusiveness with the ambitious C40 commitment to an action-oriented strategy that was transparent and addressed specific targets of greenhouse gas reduction. This strategy sought 'to empower and engage cities of all shapes and sizes to accelerate local climate action ... to meet milestones they have committed to' (Compact of Mayors, 2016).

The EU Covenant of Mayors was launched by the EU following the adoption of its Climate and Energy Package in 2008. Its energy-focused approach emphasised the need for concrete measures leading to emission reductions under a Sustainable Energy Action Plan. Its model of local commitment by local leaders was highly successful.

The role for cities expressed through the Global Covenant of Mayors and its precursor, the Compact of Mayors, can be interpreted as a significant embrace of new transitions perspectives. In addition to its explicit self-positioning in the transition to a low-carbon economy or society, there are a number of striking features.

- A focus on systemic change: city-wide socio-technical systems such as 'urban building energy use, transportation, waste and water management' offer the 'greatest opportunities' (Compact of Mayors, 2016), 'cities innovate faster ... in clean energy and low carbon infrastructure' and 'cities promote systems and actions' (GCOM, 2016a).

- Linking climate goals to wider societal co-benefits: 'cities also stand to reap great rewards' through 'lower energy costs and improve[d] mobility and quality of life' (Compact of Mayors, 2016).

- A multi-actor approach: while recognising 'local, regional and state governments to be active contributors', this is combined with an emphasis on a much more diverse set of players, 'city networks as critical partners' along with the importance of 'voluntary actions' and 'investors' (GCOM, 2016b).

- A process of managing change over time: this includes a need to 'create reduction targets ... establish a system of measurement ... publish a climate action plan ... report on progress' (Compact of Mayors, 2016). Strategic action plans are 'registered, implemented, monitored and publicly available' (GCOM, 2016b).

- A multi-level perspective: local action is given a status in its own right. 'Local leaders have a wide range of powers ... often without having to depend on action by other levels of government'. Two-way interactions with other levels are also important, 'incorporated into national strategies or used to encourage increased public or private sector investments supporting local action in cities' (Compact of Mayors, 2016). This includes 'collaboration between cities across the world, bridging gaps and building connections, as well as increasing funding to support and empower cities in their actions ... comparison between achievements ... global aggregation of the impact of city actions' (GCOM, 2016b).

The launch of the Global Covenant of Mayors consolidates the direction of policy of its immediate precursors. The role of cities and local authorities is now articulated as a key component in a challenge-led platform of actions. It foregrounds not only a relational role of city government actors with a variety of other players but also a key role for financial institutions. It can reasonably be seen as a challenge-led transitions-oriented approach to innovation using a discourse of actions and networks.

How different is the Global Covenant of Mayors to the earlier initiatives of ICLEI and C40? There are clearly some continuities but there is also a fundamental broadening of the role of the city away from that of the author of a plan-driven set of policy initiatives. There are some continuities with the emphasis on performance metrics of the earlier plan-driven approaches but now they include measurement of specific actions, a more situated version of innovation indicators, and insistence on transparency to engage a plurality of actors.

International Council for Local Environmental Initiatives

The ICLEI is the largest and longest established global network of city and regional authorities addressing sustainability. By 2010 the organisation had 200 permanent staff working in 13 different offices around the world with more than 1 000 local government members around the world. A number of characteristics of the ICLEI approach were established in its first decade of operation. Its constituency was based on local representatives primarily from environmental departments (Labaye, 2010). It promoted a plan-driven approach to local environmental policy.

Local Agenda 21 established a procedure for local authorities to identify local sustainability issues

and develop local action plans. By 2010 Local Agenda 21 had been implemented in more than 10 000 municipalities worldwide. The Cities for Climate Protection Campaign (CCP) promoted 'a Five Milestone Process' as a method for the various actions a city had to take in defining a climate strategy. ICLEI put great store by promoting a rigorous and rational standard of practice as its primary goal. According to Labaye (2010), ICLEI 'provided heads of environmental or energy departments with a reframing of existing problems in a very rational way ... the organization insisted in adopting a rigorous approach to legitimate its actions.' Moreover, according to Jeb Brugmann, 'the greatest victory of ICLEI is to have succeeded in institutionalising a standard of practice of local climate action' (Labaye, 2010). A consequence of the institutional environmental focus and the policy plan-driven perspective was that the intersections with broader economic and infrastructural roles in the city were rather limited. Connections with a broader range of innovation activities and city priorities were undeveloped and limited in their ability to promote a more ambitious strategy of global change.

From the early-2000s ICLEI sought to both broaden its remit and shift towards engagement with the top political level of local leadership. In 2003, ICLEI renamed itself 'ICLEI Local Governments for Sustainability', suggesting a desire to broaden its goals towards achieving 'tangible improvements in global sustainability with special focus on environmental conditions through cumulative local actions'. The World Mayors Council on Climate Change (WMCCC) was established in 2005, suggesting a recognition that the focus had shifted from local government environment departments to broader political leadership and 'a need to move on the climate activities from a technical approach to a political effort' (Labaye, 2010). This ultimately led to a new emphasis on the systemic nature of the changes needed along with a need for a massive upscaling and acceleration of local efforts (ICLEI, 2015).

C40 Climate Leadership group

The establishment of the C40 network in 2006 was in some ways an expression of dissatisfaction with the earlier constraints of ICLEI. Framed as an explicit response to the global challenge of climate change it was a selective network of global megacities keen to assert its significance on the world stage and to reframe sustainability as a top-level, city-wide political issue, rather than a departmental specialist environmental concern. It was a coming together of two initiatives.

- The C20 group was initiated in London in 2005, not so much as an alternative to national government initiatives but as 'symbolic leaders testing out ideas, demonstrating viability, and catalysing action by those with greater degrees of capacity' (Gordon, 2016). They could 'direct ... efforts to the delivery of working examples of greenhouse gas-reducing projects in transport, energy-generation and waste [and] use them as a catalyst'.

- The other initiative was the Clinton Climate Initiative (CCI), which was modelled on an earlier health-related programme on HIV/AIDS therapies. Its main focus was a 'marketmaking model', which promoted market transformation and joint procurement to 'unlock' latent demand for climate innovation. Paradoxically, although it argued that 'the hurdles we face are not technological, they are organisational' the intention was in fact to create demand for new technologies through 'a project-based, technology-oriented approach that envisioned cities as test beds and sites of experimentation for novel high potential technologies' (Gordon, 2016).

These two contrasting models of city-based innovation coexisted rather awkwardly until the aftermath of the failed COP 15 meeting in Copenhagen. Under the new leadership of Mayor Bloomberg and his New York team, the C40 group was transformed into an organisation that viewed itself as a key global actor on climate change rather than just a collection of 'pilots' or new markets. At the focus of this was a shared and required commitment to 'real measurable climate actions'.

From 2005 onwards, the new direction of ICLEI and the new initiatives of C40 resonated strongly with the new challenge-led policy discourse of the transition to a low-carbon society (Stern, 2006; Steward, 2012). This implied a stronger innovation focus through a new discourse of business-oriented positive actions. It led to the new orientation of a systemic approach to innovation expressed through the Global Covenant of Mayors. The city-level perspective shifted the perspective from particular technological domains to focus on end-use domains around housing, mobility and waste. Furthermore, its emphasis is not as much on the production of novel technological solutions, but rather on their widespread diffusion and actual use. By attempting to increase and intensify linkages between diverse local actors, it shows many similarities to a conceptualisation of socio-technical networks.

Academic analysis of city-led initiatives

The growing engagement and activities by cities and regions to address the challenge of climate change have been accompanied by extensive academic discussions about the particular and distinctive contribution that they can make. From a review of historical examples Geels (2011) identified three different roles: as a primary actor for promoting transition in infrastructural systems at the city level; as a seedbed for experimentation; and as a secondary player in socio-technical systems that are shaped by national incumbents.

Experiments and niches

Much of the early analysis from a transitions perspective focused on the experimental opportunities offered by specific local contexts. This was framed in terms of the multi-level perspective with regard to the creation of niches. Castán Broto and Bulkeley sought to identify 'climate change experiments' in cities across the world to explore ways in which experimentation forms part of the governance and contestation of socio-technical systems (Castán Broto and Bulkeley, 2013; Bulkeley and Castán Broto, 2013). As they observe, 'Experiments are purposive and strategic but explicitly seek to capture new forms of learning or experience [they are] interventions to try out new ideas and methods in the context of future uncertainties [and] serve to understand how interventions work in practice, in new contexts where they are thought of as innovative.' They found that 'experimentation is a feature of urban responses to climate change across different world regions and multiple sectors', which opens up new political spaces for governing climate change in the city.

Brown and Vergragt (2008) analyse what they call 'bounded socio-technical experiments' more explicitly as contributing to systemic change, while Evans and Karvonen (2011) articulate the notion of the urban living laboratory as a site for such experiments to be pursued and promoted. The attention to the role of the city as a seedbed for experiments is accompanied by a recognition that accomplishing low-carbon transitions will require the 'reconfiguration of socio-technical networks'. This points to the need to improve understanding of the dynamics and processes whereby experiments contribute to such reconfiguration. Van den Bosch (2010) presents a scheme that enables urban projects to be treated as transition experiments (rather than simply as ad hoc initiatives) through reflexive learning processes associated with 'deepening, broadening and scaling up'.

Regime variation

Späth and Rohracher (2012) go beyond the seedbed of experiments approach to propose that cities and regions offer the potential for enabling and revealing spatial variation at the systemic level of regimes themselves. Although these are acknowledged as only 'partial transformations', it is proposed that their variety offers a different type of 'transformative momentum' from that arising from niche experiments. Moreover, the diversity suggests that 'local actor networks do intentionally create and support such "deviations" from the principal characteristics of a regime'. Although such variation is constrained it can have an impact on national or even international discourses and policies of regime change.

Such 'regime deviations' may lend legitimacy to visions of more sustainable socio-technical regimes and related processes of learning, actor-alignment and institution building. Späth and Rohracher suggest that 'Cities and regions are often large enough to incorporate at least some of the systemic properties of existing regime structures (typical supply structures, relations of supply and demand, etc.). At the same time, they can be small enough to exploit the advantages of proximity for creating new actor networks, discourses and institutions for alternate socio-technical configurations. Thirdly, they often have well-established governance structures to coordinate change processes (not only city or regional governments, but often also well-organised civil society organizations and networks involved in urban or regional governance).'

The perspective of Späth and Rohracher directs attention to 'the analysis of the formation of discourse coalitions and respective networks' to help assess the potential of local activities to influence transformative niche regime dynamics. This knowledge focus on discursive mobilisation and network dynamics is rather different from that of learning from experiments. It addresses the 'agency of local actors in building social networks' and 'the discursive dynamics around alternative constellations'. It resonates with the 'primary actor' category proposed by Geels (2011).

Global embeddedness

In contrast with this emphasis on the potential of local variety of socio-technical systems to influence transitions, Truffer and Coenen (2012) stress the embeddedness of cities and regions in wider, global networks. They suggest 'a relational perspective that conceptualizes transitions as interdependent processes between territorialized, local and trans-local networks within the context of (changing) multi-scalar,

institutional structures.' They warn against privileging the locally defined system: 'a "local node, global network" perspective provides a useful heuristic for delineating systems, by following the network to wherever it leads, instead of setting system boundaries in an arbitrary and closed-off way. In other words, researchers allow transitions to define its spatial dimensions based on the way actors themselves develop relationships over space.' In particular they caution that 'Trans-local and trans-national network relations and institutional interdependencies need be acknowledged by policymakers and "transition managers" even though they may extend beyond their sphere of influence.' This seems much more in tune with the secondary role identified by Geels (2011).

Governance capabilities

It appears therefore that within transition studies there are diverse approaches to the significance and potential of the city and regional level, which differ in their emphasis on niche experiments or wider system change, and in the balance of autonomy and dependence at the local level.

Irrespective of which of these perspectives is adopted, Hodson and Marvin (2010) draw attention to the generic importance of governance capabilities at city level that influence transitions. In particular they highlight the critical importance of 'systemic intermediaries' in this process. The Climate Knowledge and Innovation Community (Climate-KIC) 'Transition Cities Project' is designed to build transition capabilities among actors within local city-wide systems (www.climate-kic.org).

Interestingly, despite the academic arguments as to the extent to which systems in cities and regions are shaped locally, empirical policy-oriented studies are surprisingly consistent in their observations on what systems cities actually address in practice. For example, a UN Habitat study of 2011, Castán Broto and Bulkeley's survey of urban transition experiments and the International Energy Agency (IEA) report *Energy technology perspectives 2016* all show that most activity is directed at the built environment, urban transport and local energy networks (UN Habitat, 2011; Castán Broto and Bulkeley, 2013; IEA, 2016). This suggests that these are perceived by local actors as amenable to local shaping as well as having significant potential for reducing greenhouse gas emissions.

5.3.3 Trade unions

Although rarely the focus of wider policy discussions on sustainability transitions, trade unions in Europe have been actively engaged with the concept of transition, and its environmental and social implications, since the early-2000s. The most visible expression of this shift has been through the idea of a 'just transition', which was incorporated into the 2015 Paris Agreement on climate change.

Examples of trade union-led initiatives

The 'just transition' and the Paris Agreement

The Paris Agreement on Climate Change includes a commitment to take into account 'the imperatives of a just transition of the workforce and the creation of decent work and quality jobs'. Interestingly, this is the only use of the term 'transition' in the entire agreement and it is a direct consequence of the lobbying efforts of trade unions internationally over a decade or more. The accompanying Paris Decision of COP 21 also highlights in more general terms the 'social, economic and environmental value' of the 'co-benefits' of voluntary mitigation actions. This recognises the political importance of positive economic, employment and other outcomes associated with measures aimed at reducing greenhouse gas emissions (para. 108).

The European Trade Union Confederation

The concept of a 'just transition' was embraced by the European Trade Union Confederation (ETUC) in 2009. The ETUC is the principal representative body for trade unions in Europe and includes 88 national trade union confederations in 37 European countries, 10 European industry federations and 60 million individual trade unionists (ETUC, 2015). The position of the ETUC on climate change issues is therefore of broad significance.

ETUC confederal secretary, Joël Decaillon, presented the perspective in 'A European approach to tackling climate change' (Decaillon, 2009), stating that 'just transition programs are the best way to guarantee that structural changes in employment patterns due to climate change mitigation are anticipated, and that the potential for new jobs is maximised, while ensuring that workers are not forced to pay for the necessary mitigation measures through the loss of their livelihood'.

Decaillon envisages that just transition programmes would comprise a number of elements. One is an anticipatory process of social dialogue on changes in employment and skills arising from transition. Another is the need for measures for retraining, alternative employment and social protection for workers displaced by transition. A fund, financed by emissions trading revenues, would provide 'assistance for workers displaced as a result of the transition to a low carbon economy'. A third element is support for general measures to promote the transition to a low-carbon economy through education, innovation and investment. Finally, there are measures for less favoured households to reduce their dependence on costly energy and transport through investments in energy savings and public transport.

The notion of a 'just transition' has been traced back to proposals from North American trade unions for schemes to address displacement of workers caused by the regulation of particular chemical products due to risk (Hampton, 2015). In other words, its genesis arose from more specific concerns predating the systemic challenge of the transitions to a low-carbon society. One of its early exponents, Brian Kohler, has recently argued that a just transition requires three elements: sustainable industrial policy; robust social protection or 'safety nets'; and wide-reaching and creative labour adjustment programmes. Of these 'a robust social safety net is an absolute prerequisite to a just transition' (Kohler, 2014). Although not exclusively focused on this topic, the just transition concept is often perceived as a 'safety-net' discourse, which is less concerned with making transitions happen than with addressing the consequences of a transition made by others.

However, another strand of ETUC engagement with transitions is more directly engaged with the emergence of the new policy discourse on transition to a low-carbon society. In fact, the ETUC played an early and active role in relation to the newly emerging discourse on transitions in the early-2000s. In 2002, in the ETUC contribution to the Johannesburg Earth Summit (Le Blansch, 2002), there was a call for 'policy responses and societal strategies, which need to deliver major transitions and reform strategies at all levels of governance. These transitions will need radical medium and long-term societal developments at all levels in order to achieve major changes in the allocation of resources, to restructure power relations and to ensure interests that are currently excluded are, in the future, included'.

The ETUC contribution states that the employment problems arising from the reduction in traditional energy sources 'must be tackled with the necessary mechanisms of fair transition to mitigate adverse and undesirable social effects'. However, this was accompanied by a much more proactive framing of the opportunities for trade unions to shape the nature of the transition itself. One opportunity was linked to training and skills, recognising that the emergence of some new sectors 'is creating significant numbers of new jobs, which will require the adaptation and training of the workers involved'. Another was the importance of employee engagement in the pursuit of energy efficiency: 'participation by employees and their representatives is essential for the success of such policies'. Trade unions have an opportunity to 'negotiate fair transitions' through 'raising competencies for workers and trade unions at company and local level' and to build 'their capacities, first of all by the process of learning by doing'. This recognises a role for workers with practice-based knowledge to contribute to making transitions happen.

This perspective was reinforced by a further report, *European trade unions as actors for mitigation of climate change* (Le Blansch et al., 2003). That report sees 'the attempt to effect a societal transition' as having many historical parallels with previous 'industrial and informational revolutions, ... in which workers organised in trade unions to negotiate fair technological changes.' This underlines the importance of 'institutionally well-embedded trade unions taking anticipating stances and involving themselves proactively in negotiating changes, for those changes to occur in an equitable and socially acceptable way'. Implementation of the Kyoto Protocol could be viewed as a 'historically unique', 'globally coordinated' attempt to effect societal transformation, stretching from the workplace to societal and governmental roles.

A more socio-technical and systemic angle on the problem starts to be evident in the report 'Climate change — avenues for trade union action', (ETUC, 2004) which talks about a 'required refocusing of production and consumption methods towards a more sustainable model'. It further specifies that 'any transition ... will entail significant changes in terms of jobs and qualifications, lifestyles, and for companies'. This new emphasis on consumption and behaviour highlights the broader systemic character of the changes required and draws attention to a much more positive perspective for trade unions than responding to negative impacts: 'It constitutes a unique opportunity

to make a social transition to improve the environment and to boost employment and well-being ... transport, housing and urban development sectors, in particular, can bring huge environmental, social and economic benefits'. Social transition requires engagement with the 'system in the broadest sense', including end-users, designers and consultants. It repositions trade unions as a core part of the transition process itself. In essence, this could be summarised as a 'negotiating change' perspective in contrast to the 'safety net' perspective.

Although the 'just transition' has become established as the dominant paradigm for trade union engagement with the transition to a low-carbon society, it continues to be a mix of the 'reactive safety net' and the 'proactive shaping' perspectives.

Academic analysis of union-led initiatives

One of the features of academic analyses of trade unions and transitions is a more explicit engagement with prevailing sociological and economic paradigms around environmental sustainability than is often found in the transition community. This includes challenging the adequacy of ecological modernisation and neoliberal market-based instruments as broad frameworks for action. A recent study of UK unions and climate change (Hampton, 2015) unpicks some of the strands within union thinking and seeks to situate them in the wider conceptual landscape of policy frameworks to address climate change: ecological modernisation, neoliberalism and Marxism. The first two of these policy approaches are echoed in the two prevalent frameworks in the wider debates on climate policy, namely state-led interventions and market-based instruments.

Hampton suggests that the only alternative to these is a Marxist model of socialist change led by the organised working class. However, the transitions framework represents an alternative perspective, which also shares an agenda of radical transformation but does not envisage its political leadership to be narrowly class based. Instead it is likely to involve a mix of public and private economic agents and to be initiated and facilitated by a range of social actors including environmentalists. It proposes reconfiguration as an alternative to reform or revolution (Geels et al., 2015b). Trade unions could play a role in such a political coalition.

The transitions framework suggests that radical transformation of social and technological arrangements will depend on a coalition of societal actors and stakeholders (Grin et al., 2010b). This can take a variety of forms and pathways, with differing degrees of coordinated or decentralised actions. One expression of this is the language of a 'radical transition'. In this approach the unions challenge the distributional effects of climate policy. In part this involves arguing that climate change is such a major threat to the whole of society that to achieve the necessary carbon reductions will require integrated and publicly owned energy supply, natural resources and transport systems. In part, too, it involves thinking more clearly about mobilisation from the bottom up.

The socio-technical transitions framework raises the wider issue of the role of trade unions as environmental actors (Snell and Fairbrother, 2010) or innovators (Räthzel et al., 2010). The degree to which this is emerging is unclear and contested. A recent European study identified much more extensive engagement of trade unions on environmental issues but saw this as combined with the traditional interests of such bodies (Eurofound, 2011). The relationship between immediate and general interests is explored in another empirical study of trade unions and jobs (Räthzel and Uzzell, 2011). It is apparent, therefore, that there is a growing academic interest in the role of trade unions as social actors within a transition to a low-carbon society. This is drawn on by the United Nations Framework Convention on Climate Change (UNFCCC) secretariat in its work on the implementation of the Paris Agreement (UNFCCC, 2016a), which highlights the value of research that systematically gathers information on trade union actions on climate change.

5.4 Knowledge and governance for transitions

5.4.1 The 'platform of actions' approach

The Paris Agreement promotes a new 'platform of actions' approach, which is aimed at non-state actors and creates a global platform of climate actions. Our review of the role of community, city and trade union groups shows a growing resonance with this broad global approach. The Transitions Network has shifted its early narrow focus on organisational process to engagement with a diverse range of projects. The Global Covenant of Mayors explicitly defines itself as a platform of city actions, not a guide to environmental procedures. The 'just transition' perspective of the European Trade Union Confederation is reflected in new initiatives to collate collective agreements and actions, in addition to conventional general policy demands.

The notion of a 'platform' emphasises a wider system in which individual initiatives need to be positioned,

but the term 'actions' affirms that initiatives should be specified and situated rather than anonymised and aggregated. This language implies a desire to create a new relational space to enable interaction between actors. Our case studies show many expressions of this at different spatial and systemic aggregations. The 'platform of actions' is an emergent practice-based discourse. As such its principles are often expressed in a tacit and indirect way. Nevertheless they appear different in nature from the conventional dualistic discourses of national government policy and market forces, or the economy and the individual. Our review of the academic literature shows more explicit conceptual framings as a counterpart, such as actor networks, socio-technical systems and patterns of practices. In knowledge terms these have a sociological relational focus, which is distinct from a mix of economics and behaviourism.

5.4.2 Two broad knowledge challenges

Despite the variety of forms of engagement with the transitions perspective, there are two prominent knowledge challenges shared by them. One is the status of 'actions'; the other is the framing of 'system'. Both tend to be treated in a tacit and indirect way but there is a strong argument for treating them explicitly and directly as key domains of governance-relevant knowledge.

Actions

In this review, the knowledge of both actors and analysts is often framed around actions, which are seen as interventions with a positive contribution to a sustainability transition. Both actors and analysts often treat them as case studies and collect 'samples' of them as a basis for interpretation or action. Actors are also keen to facilitate learning and replication of actions.

The creation by the Paris Agreement of a global platform on climate actions represents a quite new order of ambition for systematic collation of action-based data. Yet the conceptual and methodological foundations for such an innovative intervention are still in development and arise from activities by particular organisations such as the Carbon Disclosure Project or The Climate Group. This important opportunity for creating action-oriented data worldwide points to the need for more focus on developing appropriate categories and methods for monitoring actions that are relevant for sustainability transitions.

Action-based indicators are very different from the measures commonly employed in policymaking and analysis. Their qualitative and heterogeneous nature is often regarded as too daunting compared with quantitative measures. Yet the methodologies and protocols that are needed can draw on some of the discussions about developing direct innovation indicators from documentary and digital sources (Steward, 2008). Despite the challenges, they offer a richer set of resources that are meaningful to a wider range of actors and analysts.

One of the requirements for effective action-based indicators is their co-creation by actors and analysts. The detailed insider knowledge of the actor is often accompanied by advocacy and instrumentalism. The analyst lacks direct access but is able to bring more detached and explanatory skills. A productive relationship can draw on successful examples of such collaboration from qualitative social researchers.

A starting point could be a more systematic aggregation of existing case study analyses that have been undertaken by both actors and analysts.

System

It is apparent from the different actor-oriented perspectives that the notion of 'system change' is grounded in quite different perceptions of the system or subsystem being addressed. Often this is not addressed explicitly but forms part of implicit shared discourses and practices. There is a strong case for encouraging these to be much more explicit so that opportunities for influence and reach can be considered more systematically and comparatively.

Both actors and analysts deploy a variety of system framings at multiple levels, including sustainable production and consumption, urban systems, the food-energy-water nexus and the circular economy. Although it is evident that the academic literature displays a lively theoretical debate as to the robustness and explanatory power of these different system framings, there is also a tendency for fragmentation into separate sub-communities, which each work within just one of them. From the perspective of sustainability transitions more generally this may stand in the way of the development of more widely shared concepts and strategies.

The urgent need is for a meta framework using a set of shared concepts within which these different system approaches can be positioned. The intention is not to impose unrealistic integration but to encourage a common discourse among systemic and transformative action-oriented approaches. This needs an articulation of the way in which core concepts of system, action,

transition and transformation are deployed. Visual mapping of different system approaches might be a useful starting point.

5.4.3 Shared governance practices

The diverse range of actors that have been reviewed in this chapter all make some demands on the formal governance system of public policy, but they are often different in nature. Community groups, cities and trade unions occupy a variety of policy networks with different modes of governance. These elicit a variety of styles of influencing the established mainstream policy process. However, they also share an active interest in the challenges of governing their own action initiatives and collectives of actors. What is of particular interest from the present review is that there seems to be an active interest in a set of new and participative governance practices, which are broadly shared by this diverse range of actors. These are pursued to differing degrees with varying enthusiasm, but nevertheless are widely present.

These governance practices have been articulated through recent reviews on transitions competence and capabilities. The Netherlands Transition Competence Centre set up through the Knowledge for Systems Innovation programme identified a number of broad transition competences and these have subsequently been taken up and developed by the Climate KIC Professional Development Programme and Transitions Hub. There are four broad competences that appear frequently in the action-oriented domains reviewed and merit deeper consideration: visioning, experimenting, networking and navigating.

Visioning

Engagement with the future is a central feature of action-oriented approaches. This engagement sometimes appears to share similarities with conventional technology forecasting approaches, for example through notions of 'scenarios' and 'roadmapping'. But its core approaches represent a different action-oriented perspective within the broad sphere of foresight approaches.

One fundamental strand in this is the notion of backcasting. Instead of extrapolating current technical trends, it identifies future desirable sustainability goals or targets and seeks possible routes from the present to that future. This has increasingly been termed a 'challenge-led' approach, in contrast to a technology-driven one. It suggests a future that is socially made rather than technically determined.

Accompanying this shift has been a growing reflexivity in the process of thinking and visioning about the future. A prominent expression of this is the field of the 'sociology of expectations' (van Lente, 1993), which has turned its critical gaze on the way in which technological promises emerge and are promoted (Borup et al., 2006). Patterns such as the 'hype-disappointment' cycle are analysed and in some cases developed as consultancy tools (Pollock and Williams, 2016).

In contrast with this academic emphasis on critique, many practitioners are concerned with promoting visions to inspire and motivate action. Related to this more constructive perspective, there is growing interest in the role of discourse in developing shared visions of the futures. Work on narratives, storylines and 'imaginaries' is increasing deployed, not simply as a critical tool but as knowledge that could enable more effective transitions in practice. The more interpretive constructivist approach to visioning the future contrasts with the traditional scenario modelling approaches. Many of the action-oriented perspectives reviewed operate through an uneasy accommodation with these different perspectives. This needs to be addressed more clearly than is often the case (McDowall, 2014b).

Experimenting

The notion of experimentation is pervasive in the action-oriented approach. In contrast with its science-based origins, in the action-oriented context experiments are seen as attempts at 'learning by doing' in what is often a messy and uncontrollable social context. A recent overview argued that experimentation is one of the central concepts of sustainable transitions, although it is very wide ranging in nature (Sengers et al., 2016). Defining an experiment as 'an inclusive, practice-based and challenge-led initiative which is designed to promote system innovation through social learning under conditions of uncertainty and ambiguity', the study found 170 papers on such experiments published over the past 20 years.

Different theoretical and analytical orientations are reflected in notions of 'niche experiments', 'bounded socio-technical experiments', 'transitions experiments', 'grassroots experiments' and 'sustainability experiments'. As well as drawing on various conceptual backgrounds, these different forms of experimentation also emphasise roles for diverse actors — 'regime outsiders', civil society, or 'frontrunners'. Of particular interest are studies that seek to identify the processes of learning from experiments for wider change. Van den Bosch (2010) outlines an interesting framework

for deepening (understanding a specific situation), broadening (learning in different contexts) and scaling up (linking to wider regime changes).

There has been a very active interest in experiments from spatial and urban studies perspectives. The concept of the 'living laboratory' has become widely used and has been interpreted in relation to a key strand of laboratory studies linked to associational sociology and actor network theory (Karvonen and van Heur, 2014).

The commonalities of experimentation are perhaps of greater interest than its diversity. Sengers et al. (2016) identify some key shared characteristics, specifically a focus on the socio-technical, a context of system innovation and an orientation to challenge-led, practice-based approaches. This represents an important step in delineating an emerging domain of knowledge on experiments, which deserves further attention. The authors also observe the potential importance (as yet little developed) of research designs that bring together 'great numbers of experiments in databases to find patterns'. This links closely to the need for better research on qualitative case studies and action indicators. It also needs a co-creation partnership between analysts and actors that may not be enthusiastic about being treated as experimental subjects.

Networking

The third domain of practice present in the action-oriented perspective focuses on the process of network building. This is seen as central to the dynamics of system innovation for new sustainable regimes. Some of this draws upon broader streams of knowledge. The communities and 'networks of practice' approach from organisational studies addresses the enrolment of new practitioners through a participative learning perspective (Brown and Duguid, 2000). This is accompanied by a wider range of participative methods for stakeholder engagement in policy processes.

Studies of innovation address cluster development, value chains and innovation ecosystems. Although often largely framed from a technology-driven and firm-centred viewpoint, these approaches are fundamentally systemic in nature. They are beginning to be deployed in a challenge-led and societal transition fashion (Steward, 2015).

More explicitly arising from the modern transitions community is the promotion of a variety of network-building approaches. Reflexive learning (van Mierlo et al., 2010) is a framework focused particularly on individual learning processes. The notion of the 'transition arena' (Loorbach et al., 2008) is a deliberative form of policy intervention to engage a diverse range of stakeholders in shared purposive transition actions. Mixed methods of stakeholder participation and social network analysis (Matti and Steward, 2016) are being applied to socio-technical system mapping to facilitate city-wide, challenge-led transition clusters. Social network approaches highlight the role of boundary spanners in the network-building process and have led to considerable attention to the particular role of intermediaries in enabling transitions (van Lente, 1993).

What all of these approaches share is a focus on a situated meso level of arena and system in contrast with the micro focus of the 'experiment'. The definition of these meso-level networks is treated as an interactive process between actors and analysts. Although this can be seen as an interesting commonality, it is usually pursued in specific pragmatic contexts. It has yet to be articulated in a more effective and general manner. From an action-oriented perspective, a priority is promoting participation through enrolment of stakeholders in a shared vision to provide an alternative dynamic for change from below. Peer-to-peer learning is a key part of this process.

Navigating

A shared concern in the action-oriented approach is the challenge of making transitions happen through particular pathways of change. Many actors still deploy conventional narratives of rational, deliberate actions on strategy and policy. Yet this is accompanied by a discernible deeper shift towards recognising that the purposive action needed for transition is likely to be more complex and contingent. This contrast between planned and adaptive strategies for change is relevant to all types of social actor.

Interestingly much of the knowledge base for this draws on organisational change, business strategy and policy. This was initiated by the notions of emergent versus deliberate strategy (Mintzberg and Waters, 1985) and those of disjointed incrementalism or 'muddling through' (Lindblom, 1959), and has led to a new action-oriented approach to 'strategy as practice' (Jarzabkowski and Spee, 2009). One of the consequences of this has been a reframing of strategic intervention as more akin to steering than control (Hampden-Turner, 1990).

In the transitions perspective this is articulated most explicitly as a process of navigation (Jørgensen, 2012). The dynamics of transition involve a complicated

mix of a variety of processes of path creation (Garud et al., 2010) and regime destabilisation (Turnheim and Geels, 2013). While plausibly bundled under broad notions of co-evolution, an action-oriented approach needs more detailed and articulated guidance as to the process of navigating transitions. In terms of contributions that assist this process, the transitions and innovation communities offer insights into identification of key branching points (Foxon et al., 2013), appraising diverse options and exercising choices between opening up and closing down (Stirling, 2008).

Yet the knowledge base for navigating transitions needs much fuller development. Many of the concepts have been derived from studies of focal actors that are large businesses or national governments. These need elaboration in relation to systemic interaction among a diverse range of less established societal actors.

5.4.4 An inclusive framework?

Each of these different governance practices has a rich terrain of innovative action and novel thinking. All of these dimensions of transition competence have associated emerging domains of knowledge. Yet these domains are often rather fragmented and not treated as part of such a broader overall perspective. Such knowledge develops at the interface of actors and analysts and usually draws upon quite specialised academic approaches. An endeavour to articulate this knowledge base in a manner that successfully addresses the variety of practitioners in this review could be of great value. This is not simply a different approach to be adopted by academic researchers. It requires the development of a knowledge community with co-production between actors and analysts.

5.5 Strengths and weaknesses of the action-oriented approach

The strengths of the action-oriented approach are as follows:

- It focuses on the role of agency expressed by non-state actors. This acknowledges the considerable extent of actions for sustainability worldwide that are promoted by these actors in practice. Other approaches frequently treat these actions as, at best, partial, and often as marginal or insignificant compared with mainstream policies of national governments or economic market signals. When their extent is recognised, it is still subsumed within the prevailing economic or behavioural paradigms. An inductive, empirically led approach therefore captures and respects an important domain of social action, which tends to be either sidelined or incorporated by mainstream deductive, theory-driven approaches.

- It demonstrates a cognitive mix of practice-based and academic knowledge. The focus on social actions rather than academic concepts recognises the role of a wider pool of knowledge constructs arising from the sense-making and discursive practices of organisations trying to make sustainability happen. The action-oriented perspective offers substantive ideas regarding sustainability transitions, which express prevailing concepts and narratives of transformative change, informing and arising from prominent domains of action. These often try to connect with the rather few domains of social science that seek to explain change rather than continuity, such as innovation studies, behavioural economics and historical dynamics (tipping points). They engage with the actual dynamics of process change ('opening the black box') rather than just observing the variance between inputs and outputs.

- There is a shared core practical and conceptual engagement with the relationship between situated action and systemic transformation. A key challenge recognised by many of these action-oriented perspectives is how to combine their situatedness with wider change. Although individual or economy-driven theories are still often utilised, either explicitly or tacitly, there is growing interest in alternative theorisations such as socio-technical systems or practices. Conventional notions of diffusion and scaling up are increasingly seen as inadequate. The traditional categories of cumulative, cooperative and consensual processes in the transformative dynamics of polycentric systems are being rethought.

- Place-based approaches are given a central role in the process of transition. The new action-oriented transitions discourse has proved to be particularly appealing to place-based actors, whether in civil society (community groups) or subnational governance arenas (cities and regions). This reflects the pursuit of interest in a space between the conventional domains of the individual and the national state — a space where extensive action is actually happening. A consequence has been a host of practical initiatives along with active attention and engagement from the emerging transitions-focused academic community. As well as recognising this reality, the action-oriented perspective offers persuasive explanations of how the 'local', and the 'place' provide more plausible prospects of linking actions with system change.

- New modes of participative governance are explored and promoted. The action-oriented approach is associated with widespread initiatives for innovation in governance towards more networked and participative modes. These represent a quite different perspective from the conventional 'drivers and barriers' framing of policy reform, which is grounded in a quasi-evolutionary 'variation and selection' conceptualisation. Instead they draw on a constructivist, associational and interactivist theoretical repertoire. They are grounded more in relational sociology than in evolutionary economics. There is less reliance on market-based instruments and more interest in creating actor networks.

- A key feature is a celebration of the power of the 'exemplary' case study. Whether expressed as 'grassroots innovation', 'best practice', or 'disruptive innovation' this is a radical alternative to a limited remit of change in general framework conditions (e.g. prices, regulations, and research and development intensity), which avoids promotion of specific pathways. It expresses a remarkable convergence between the action-oriented perspectives of very diverse actors from community, city or business networks. It is quite different from the widespread conventional policy and economy approaches. It emphasises agency over constraint, solution over problem. Key challenges are the selection criteria used to identify exemplars, the choice of appropriate analytical framework and situating individual cases within wider patterns.

The weaknesses and less developed parts of the action-oriented approach are as follows:

- The action-oriented approach provides an uncritical and overoptimistic view of the role of non-state actors. Advocating for the significance of particular actors has a lot of merit in terms of broadening approaches and focusing attention on new potential opportunities. For some, the role of non-state actors is seen as a viable alternative to official government action. For many, however, it is seen as significantly different but complementary. However, this needs a degree of reflexivity combined with engagement. The implications of this apply to both the non-state actors themselves and the academics who have chosen them as the focus of their research.

- The cognitive mix between practitioner-based and academic approaches is often rather uneven and unbalanced. Practitioner-based perspectives may not acknowledge the wider intellectual sources from which they are drawn. Academic approaches may often promote an overly narrow positioning, driven by disciplinary and institutional imperatives. A shared dialogic approach of practitioners and researchers is frequently underdeveloped and ways to promote this deserve more attention.

- The interface between actions and system, while foregrounded, is treated rather inconsistently. The 'alternativist' perspective (of some actors and analysts) simply views system change as a secondary consequence of bottom-up actions. More widespread multi-level, interactionist approaches are dissatisfied with a simple cumulative model but seek other options in too eclectic or tacit a fashion. This is often not helped by the evaluation criteria of funders. A consequence is the persistence of economic or behavioural paradigms that are predisposed to privilege either the market or the individual as the key explanatory variable. This may arise through tacit deference by actors or by a more explicit appropriation by dominant knowledge communities. The rapport with relevant sociological research, which starts from a heterogeneous, interactive, relational perspective, remains undeveloped. The facilitation of a more active engagement with this knowledge base is crucial.

- There is little attention given to non-place-based approaches to systems and networks. Recent framings from business and innovation studies, such as value chains or global innovation networks, either receive little attention or are actively rejected. This is an obstacle to less place-based actors, such as businesses and trade unions, engaging more fully with the new transitions discourse. It is possible to trace a number of actors in these spheres increasingly deploying the concepts and discourse of transitions. These actors have weaker links with the transition studies community and their accompanying academic strands draw more on traditional social science domains, such as industrial policy, political economy and industrial relations. Nevertheless they exhibit growing potential interest in system transformation in tune with the new transitions policy discourse.

- An unfortunate counterpart to the innovativeness regarding transition governance practices is a weak connection with formal governance structures. At its worst this is presented in an antagonistic fashion (board room versus city hall, community versus local authority) rather than as new opportunities for interaction. Often it is simply not addressed at all and advocacy trumps reflexiveness. In what is generally recognised as a multi-actor multi-level governance system, this is a serious limitation. There is also a rather undiscriminating approach with respect to different types of non-state actor.

Formally constituted city authorities, legally incorporated companies, informal associations of residents are all very different entities with regard to their legal status and the resources at their disposal.

- The role of the exemplary case study often becomes expressed as advocacy of the 'best' solution. Yet there is no fundamental reason why the exemplar should not be combined with promotion of 'variety' as a key goal for a transition approach. This is an area where the action-oriented perspective is often not very clear. The role of innovative leadership needs a more subtle treatment of the contribution of both successes and failures. The practitioner's 'story' and the academic 'case' are often too far apart. The importance of the exemplar is not in contradiction with the need to understand and address patterns and trends. This is at the heart of the newly emergent 'platform of actions' approach, which has much potential. Yet at present it is combined with a serious underestimation of the scale of the practical and conceptual challenge that this represents. A new synthesis, which aggregates cases and combines 'action' and 'system', remains a strategic lacuna of the action-oriented approach.

6 Integrated assessment modelling approaches to analysing systemic change

Detlef van Vuuren and Andries Hof (Utrecht University)

6.1 Conceptual background and assumptions

Model-based scenarios are an important tool for assessing the changes needed to meet environmental and social targets, and for comparing possible developments in the absence of such changes. In assessing these changes, we need an understanding of all kinds of interactions. These include the complex interactions between key elements in human and environmental systems, such as growth of populations and economic output, technological change, and the global cycles of carbon and water. They also include linkages across scale (e.g. from global to sub-national levels) and economic linkages, which can occur as a result of changes in relative prices (e.g. shifts in economic activity from carbon-intensive to carbon-extensive sectors).

These different types of interactions are modelled in 'integrated assessment models' (IAMs). The results of IAMs have been used to support policymaking processes that address climate change and other global sustainability challenges (Nakicenovic and Swart, 2000; Riahi et al., 2012; Tavoni et al., 2014; van Vuuren et al., 2011; Weyant et al., 1996).

The term 'integrated assessment model' conveys the notion that this type of modelling integrates knowledge from different disciplines and aims to support policymaking, even in situations where it is difficult to produce exact answers (i.e. it is based on 'assessment' if needed). In the literature, a very wide range of models have been referred to as IAMs, including, for instance, the system-dynamics models used to study sustainable development problems (Meadows et al., 1972); models used to study air pollution (Amann et al., 1999) and numerous models addressing climate change (e.g. DICE and GCAM by Nordhaus (1992) and Edmonds et al. (1994), respectively).

In this context, we define IAMs as simplified, mathematical models that represent interactions between human and physical Earth systems for the twin purposes of informing decisions and advancing scientific understanding related to global environmental change (Figure 6.1). Such models provide a unique contribution to understanding global environmental change problems, including climate change, because they represent interactions between complex human and physical Earth systems and thereby create knowledge that would otherwise be unavailable based on the findings of individual disciplines.

In this chapter, we briefly discuss some of the main characteristics of IAM analysis and its strengths and weaknesses. Climate research examples are often used to illustrate the use of IAMs and their strengths and weaknesses. Nevertheless, most of the findings are more generally applicable.

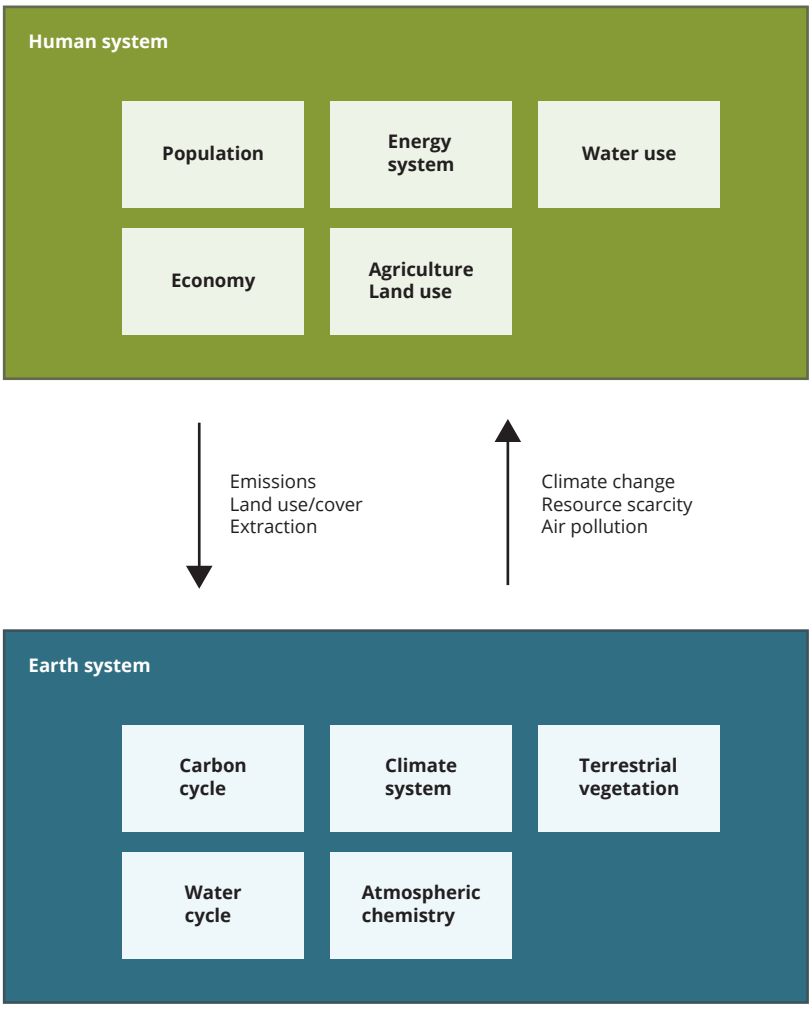
6.1 Disciplinary backgrounds and systems covered

Both the wide range of models referred to as IAMs and the integrative nature of these models imply that the disciplinary background of IAMs is not rooted in a single science. However, a key concept of IAMs is the aim to quantify existing relationships, implying that the most important contribution comes from scientific disciplines with a quantitative orientation.

The most important disciplines contributing to the IAM literature are macroeconomics, engineering science, environmental science, Earth system science and so-called 'operational science'. Many IAMs draw upon insights from a combination of these disciplines, although within the IAM field there are specific modelling approaches that are more connected to one particular discipline more than to others.

As illustrated in Figure 6.2, the most important sub-categories of modelling approaches that are

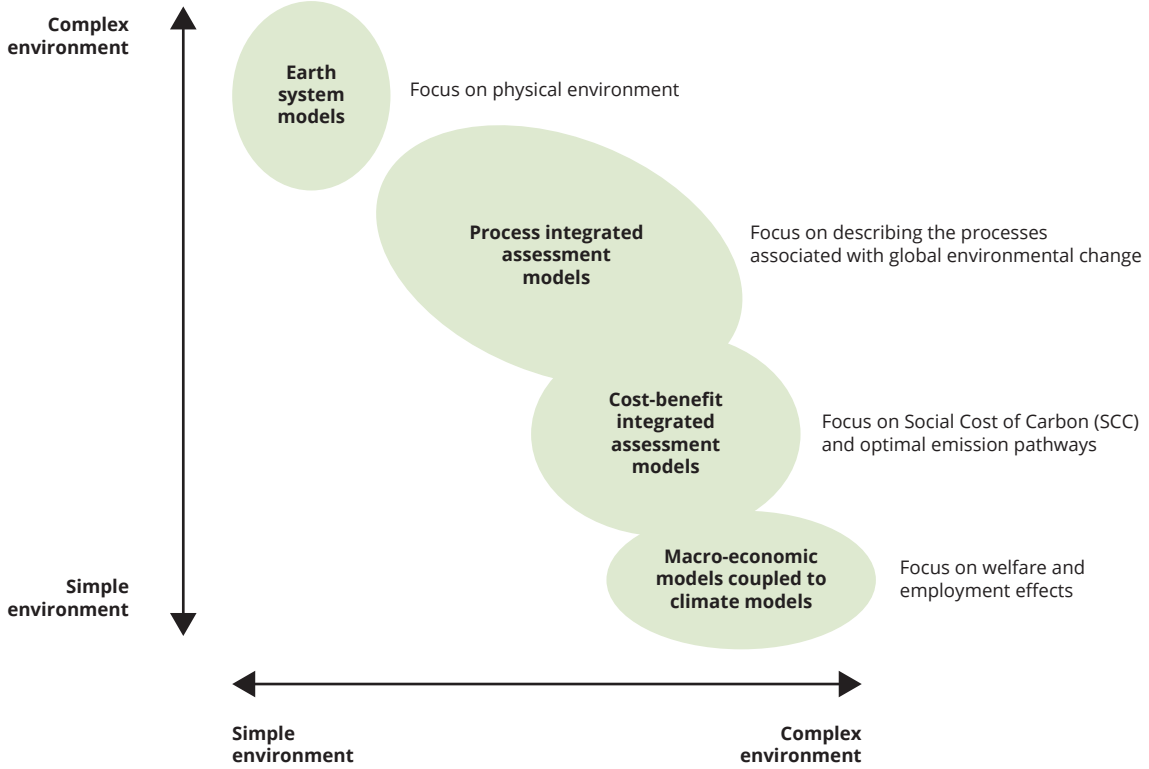
Figure 6.1 Typical representation of an IAM model



commonly referred to as IAMs in the literature include:

- Process IAMs: These models aim to describe the processes associated with global environmental change. They typically include a detailed energy system and agricultural system, an economic model, a climate model and sometimes a land cover and water use model. The disciplinary background of these models includes all the disciplines listed above.
- Cost-benefit IAMs: These models describe mitigation costs, impacts of climate change and adaptation costs to find an optimal response strategy with the corresponding social cost of carbon.
- Macroeconomic models coupled to climate models: These coupled models aim to provide insights into the impact of possible climate changes

Figure 6.2 Key types of global models



Note: IAMs aim to describe both environmental and human systems. Earth system models focus almost exclusively on the natural system. Other models, such as economic models, focus almost exclusively on the economic system.

Source: Adapted from Stehfest et al., 2014.

Box 6.1 Other modelling approaches

Many other models are used to describe possible future transitions. For example:

- **Earth system models** describe the function of the natural system. Examples include climate models (possibly coupled to carbon cycle and vegetation models) and hydrological models. These models can be used to explore the environmental impacts of transition scenarios if outcomes of IAMs are used as inputs to the scenarios.
- **Macroeconomic models,** of which there are several types, including computable general equilibrium (CGE) models and input-output (I/O) models. CGEs are often used to look at the macroeconomic impacts of long-term policies, including environmental policies. As noted above, coupling a CGE with an Earth system representation can be regarded as an IAM.
- **Agent-based models** aim to simulate the actions and interactions of autonomous agents (both individual and collective entities, such as organisations or groups) to assess their effects on the system as a whole. Agent-based models have also been developed to describe transitions towards more sustainable futures. For example, the MATISSE model developed by Köhler et al. (2009) looks into the interactions of key agents in the transport system to describe possible transitions. The advantage of agent-based models, relative to IAM models, is that the decision-making process itself can be simulated. However, data limitations often limit model calibration (see Section 6.2.3).

or of changes to climate policy on welfare and employment. They therefore include a thorough description of the economy as a whole, often with a detailed sectoral breakdown.

6.1.2 Key assumptions, input and output variables in IAMs

IAMs typically aim to provide information on the future development of energy and land use systems, and associated implications for land cover changes, greenhouse gas emissions, air pollution and (increasingly) water scarcity. The models also provide information on the economic effects of climate policy. This is done on the basis of assumptions on economic growth, demographic change, technology development, resources and policies.

IAMs often generate results based on an assumption that actors will minimise costs to within the constraints that are set. Examples of such constraints include targets such as limiting the increase of global mean temperature to less than 2 °C with a certain probability, or halting biodiversity loss. In cost-benefit IAMs, the target itself is calculated by maximising economic welfare (or minimising the net present value of abatement costs, adaptation costs and residual damage).

The scenarios created by IAMs should be interpreted with caution. Recognising all the uncertainties that exist with respect to issues such as technological developments and social preferences, IAMs can provide insights into possible future pathways but should not be interpreted as forecasts. Many policy-response scenarios should be seen as somewhat idealised future pathways that minimise the costs of achieving different targets but disregard many social and political forces that can influence the way the world evolves. Moreover, IAMs cannot project 'extreme events' such as the oil crisis of the 1970s. IAMs rely on mathematical equations, variables and parameters to quantitatively describe societal and Earth system changes that, in addition to price-driven and technological factors, influence model outcomes.

6.1.3 Geographical and temporal focus

There are many forms of IAM and their analysis can cover the global, regional, national and even the local scale. The most well known models are the global models, which typically distinguish between 10 and 30 world regions. As IAMs focus on long-term processes, their typical time horizon is at least to 2050 (i.e. 30 years into the future), but for climate change often a longer time horizon is used (up to 100 years or more). Relationships are usually based on historical data.

6.2 Conceptualisation of transitions

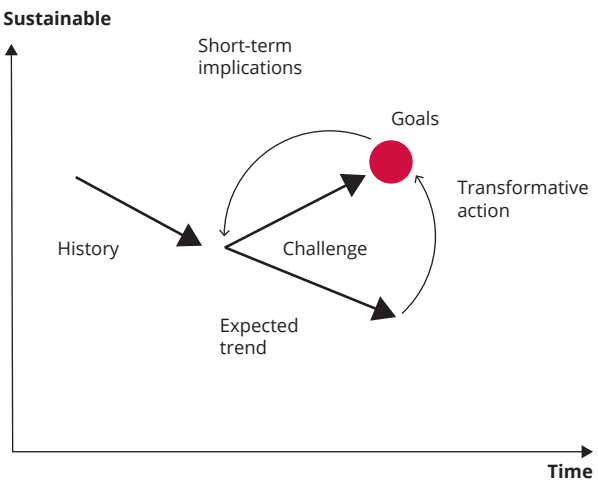
6.2.1 Overall dynamics of transitions

Typically, IAMs describe two key sets of scenarios: those that explore possible developments given a set of key assumptions; and those that focus on how to achieve specific targets or end situations. Several related terms are used to identify these two categories of IAMs. In this chapter, we refer to them as 'explorative scenarios' and 'normative scenarios'.

Explorative scenarios are projections of greenhouse gas emissions and other sustainability indicators as they might evolve in a future in which no explicit actions are taken to achieve long-term sustainability targets. Most of them are so-called 'baseline scenarios', that is, scenarios that assume no new policies targeting the policy area that is being analysed. These baseline scenarios play the important role of establishing the projected scale and composition of the future energy, economic and land use systems as a reference point for measuring the extent and nature of required action for a given sustainability goal. Accordingly, the resulting estimates of required effort and costs of a particular transition scenario are always conditional upon the associated baseline. These scenarios are sometimes also referred to as reference scenarios.

Normative scenarios are scenarios in which specific targets (such as climate targets) are achieved. These scenarios focus on the required action, costs and benefits of achieving these targets. A specific type of normative scenario explicitly applies a backcasting approach: here a set of future goals is agreed upon, while the model is used (possibly in combination with storylines) to explore what would need to change to achieve these goals (Figure 6.3).

Figure 6.3 The backcasting approach



Source: van Vuuren and Hof.

Simplifications and their effects

Usually, the changes (policies) introduced in the normative scenarios are simplified to make them transparent. One such change could be the introduction of a global price on carbon. Such a policy would induce subsequent changes in the energy and land use systems and in economic growth.

In order to simplify the dynamics involved, IAMs typically assume fully functioning markets and competitive market behaviour, meaning that factors such as non-market transactions, information asymmetries and market power influencing decisions are not effectively represented. The scenarios are often based on cost-optimisation.

Models use different algorithms to achieve targets. Some models assume perfect foresight, meaning that economic actors make decisions with complete certainty about the future costs and benefits of their choices. As such, a perfect foresight model could identify the optimal investments in 2020 to achieve an emissions target in 2050 with the lowest costs in the 2020-2050 period. However, perfect foresight models are usually more computationally intensive and therefore have less detail, especially with regard to the physical system.

In contrast, recursive-dynamic models assume that economic actors make decisions at each point in time based only on the information available during that time period. So, investment decisions in 2020 would be made only on the basis of information in 2020. However, by running a number of iterations, recursive-dynamic models can also be used to identify least-cost pathways for long-term targets. As the recursive-dynamic approach is less computationally demanding (for so-called solvers) than perfect foresight models, it allows for more detail and, particularly, complexity in the underlying systems. However, recursive-dynamic approaches have much less certainty of finding the 'optimal' solution.

IAMs make other simplifications. For example, they do not take power struggles into account explicitly, although results can help to identify where power struggles may occur (for instance in scenarios that show a very rapid phase-out of coal-fired power plants). IAMs generally also treat transitions as smooth, goal-oriented processes. This is in contrast with socio-technical studies, which regards unexpected events and chaos as the rule rather than the exception. This does not necessarily imply that IAMs are over-optimistic about the speed of transitions, as unexpected events can have an accelerating effect. A good example is the German feed-in tariff, which gave such a boost to solar photovoltaic power production that costs decreased much faster than had been anticipated in most IAM scenarios. Indeed, historical transitions at the global scale have sometimes been faster than those shown in IAMs.

As a result of the simplifications in models, there are various examples of scenarios that were proven wrong. In most cases, examples can be found of scenarios being either too optimistic or too pessimistic about future development. One example is the emission trends included in the Intergovernmental Panel on Climate Change (IPCC)'s Special Report on Emissions Scenarios (SRES), which were developed in 1997 and 1998 and published in 2000. The estimates of emissions in 2000 were found to be too high, because the full impact of the economic crisis in East Asia during that period was not included and they also overestimated emission growth in the countries of the former Soviet Union. In the 2005-2010 period, however, the SRES projections were considerably lower than real emission trends as a result of rapid emission growth in China.

Similarly, researchers have also highlighted the underestimation of photovoltaic capacity in successive scenarios of the International Energy Agency (IEA) (Witajewski-Baltvilks et al., 2015). In general, this underlines that model-based projections are not meant as forecasts but instead represent tools for exploring possible futures, including potential transition trajectories.

6.2.2 Core drivers

The core drivers of the baseline scenarios in IAMs are assumptions on population and economic development, policies and governance, societal trends and lifestyle change, and technological development.

In normative scenarios, specific incentives (usually policies) are implemented to ensure that the targets are met. A commonly applied 'incentive' in model-based research is a global uniform carbon tax or price applied to all sectors and regions, assuming cost-optimisation across sectors and regions, and sometimes across time periods. Introducing a price-based incentive into the scenario does not necessarily imply that the scenario results are only relevant for that policy instrument. Rather, the model provides insights into the types of measures that could be implemented to achieve a policy target (e.g. a significant increase in wind power).

To provide insights into more realistic second-best situations, some studies have included scenarios that simulated delayed or fragmented policy implementation or limited the introduction of new

technologies (Kriegler et al., 2014b, 2014c, 2013; Tavoni et al., 2013). Once the policy is adopted, its effectiveness is generally assumed to be unaffected by the institutional framework — which is a general characteristic of IAMs. A few examples of IAM studies exist in which the effect of specific sectoral policy measures are estimated (Deetman et al., 2013, 2015).

6.2.3 Core actors

The representation of non-technological factors, such as interactions among actors and interest groups, political economy factors, and institutions is rather stylised in models, as they are more difficult to capture in the mathematical equations. Similarly, models lack detail in the representation of consumer behaviour and external drivers affecting policy effectiveness, such as actor heterogeneity, institutions and governance. The representation of governance and institutions is limited to the actions of the state or the government, generally represented as a social planner implementing regulations and policies. Particularly in the most aggregated economic IAMs, a single, global cost-minimising actor is usually assumed.

In the more complex process IAMs, the equations represent many decisions. Many of them can be seen as representing individual actors (e.g. power companies, house owners, commuters). However, most of the time the decision is translated into choices based on the costs and benefits of options. The specific interests of actors are not included. Decisions about technologies are made based on the relative costs of an ensemble of choices that are specified per region and vary dynamically over time or are manually changed exogenously by a social planner.

The relative costs of alternative choices can consist of explicit costs factors (e.g. capital, operating and maintenance) and implicit cost factors (e.g. preferences). While this implies that technology economics are combined with actor-based preferences, it remains the case that models normally translate decisions into comparisons of costs and benefits. This tends to exclude from consideration more value-related preferences (e.g. vegetarian diets versus meat consumption) or appreciation of risk.

Very heterogeneous sectors (e.g. households) with lots of different technology and behaviour parameters are also more difficult to represent than more homogeneous sectors such as electric power generation. However, some IAMs have either explicitly or implicitly addressed the role of different actors and actor heterogeneity, as reviewed by Krey (2014). Examples of heterogeneities reflected in models include the urban-rural divide, income distribution, or household composition (Ekholm et al., 2010; Eom et al., 2012; Krey et al., 2012; Melnikov et al., 2012; O'Neill et al., 2012; van Ruijven et al., 2011). Other attempts include the prescription of specific types of behaviour, such as dietary change or more environmentally friendly lifestyles (Stehfest et al., 2009; van Sluisveld et al., 2015) and more explicitly indicating different consumption groups. The latter, for instance, includes work that distinguishes different consumer groups based on their transport decisions (i.e. early adoption of technology versus slow movers) (McCollum et al., 2016).

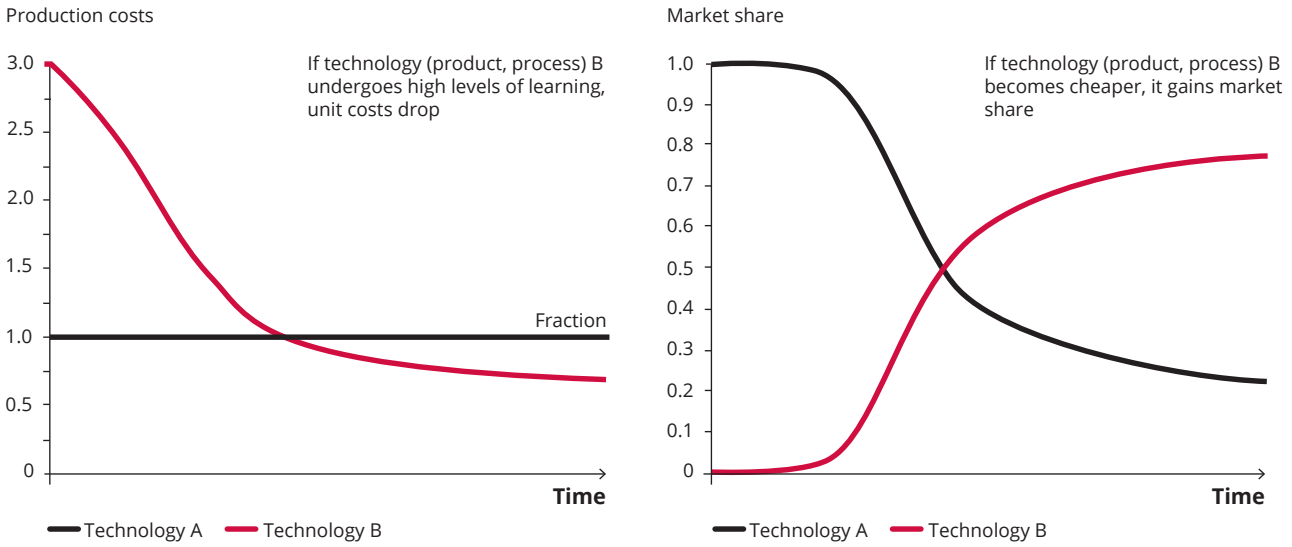
There are also agent-based models that describe the co-evolution of human-earth systems. Typically, these agent-based models tend to be limited by data — a problem that is tackled by either describing more hypothetical systems or focusing on somewhat simplified systems. The advantage of agent-based systems is that they are more easy to relate to some of the social science-based literature on transitions. An example of an agent-based model is the MATISSE transport model, which represents different transport behaviour (Köhler et al., 2009).

6.2.4 Phases of transitions

In many IAM scenarios transitions are an emergent property: the changes in technology application over time emerge from the input variables (both exogenous and policy induced) and the model structure. A key exception is that in optimisation models, the rate of change of introduction of new technologies is often constrained using the s-shaped introduction curves observed historically.

The emergent description of transitions results from either endogenous behaviour (e.g. the phasing out of oil in the case of rising oil prices due to constraints on oil resources) or policy-induced variables (e.g. carbon price promoting a shift towards renewable energy). The resulting changes often follow the trajectories of historical transitions, with a slow onset when the new technology is barely competitive, followed by rapid growth and finally market saturation. Obviously, in models these processes need to be translated into equations, for instance, representing the preference for low-cost technologies (e.g. an optimisation algorithm choosing low-cost technologies, or equations assigning market shares on the basis of an appreciation function including costs), inertia (e.g. formulas representing capital turnover or maximum growth constraints) and technological learning (e.g. prescribed performance trajectories or 'learning-by-doing' formulas). Figure 6.4 provides some indications of possible model outcomes.

Figure 6.4 Some key transition processes over time in a simulation model



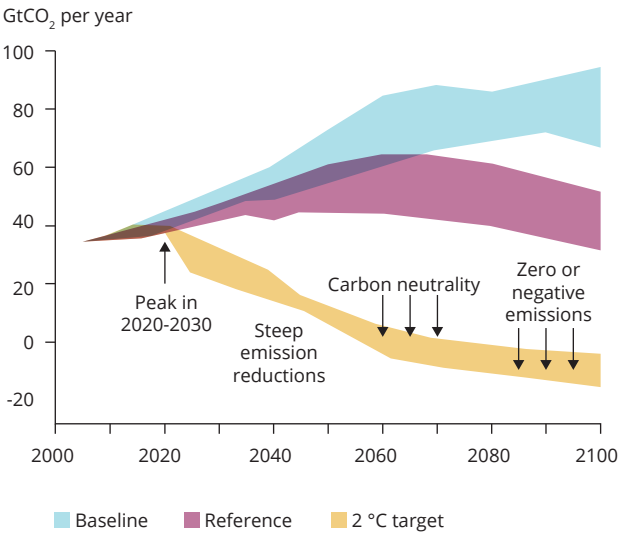
Source: van Vuuren and Hof.

Most IAM studies have been on the subject of climate policy and, more specifically, on achieving stringent climate targets. Interestingly, some similar results can be seen at the level of economy-wide emissions across a range of models, which can be summarised in terms of phases of the global emission trajectory (Figure 6.5).

This focus on phases of transitions can provide particularly useful insights for policy, illustrating the urgency of action quite forcefully. Scenarios often distinguish between four different transition phases:

- The first phase (especially interesting from a political perspective) is the period up until the point at which global carbon dioxide (CO_2) emissions must peak. Most scenarios indicate that this must occur around 2020 and certainly before 2030.
- The second phase consists of a period of strong decrease in CO_2 emissions.
- In the third phase, which has to occur at around 2060-2080, emissions have to be near zero (carbon neutral).
- The final phase, at the end of the century, consists of net negative CO_2 emissions, which can be obtained by reforestation and use of bio-energy with carbon capture and storage (BECCS) technology.

Figure 6.5 Phases of transitions



Source: Tavoni et al., 2014.

6.2.5 Main barriers

Several barriers are introduced into IAMS, either explicitly or implicitly. Some barriers can be grouped into three clusters technical factors, economic factors, and social factors (although these groups strongly overlap). As described in more detail below, technical barriers include inertia, system requirements and technological readiness; economic barriers include cost barriers, sectoral shifts and rebound effects; and social barriers include societal preferences.

Technical barriers

Inertia in transitions is modelled by either including specific vintages in the capital stock or by assuming a maximum emission reduction rate (e.g. resulting from s-shaped diffusion curves for new technologies). Vintage-based models typically assume that existing capital stock is only replaced after its technical or economic lifetime. However, the economic lifetime may be influenced by policy. For example, a carbon tax could decrease the economic lifetime of a coal-fired power plant.

System requirements are an important barrier in transitions to a low-carbon society. For a reliable electricity network, there is a need to limit the proportion of intermittent renewable energy capacity, create sufficient flexible backup capacity, and/or extend the grid so that more electricity trade is possible. IAMs (either implicitly or explicitly) take into account these system requirements by analysing the whole system (e.g. the region's entire electricity system).

Technological readiness can be simulated by IAMs by allowing only certain technologies to be implemented from a certain year in the future. This is usually done for technologies that have not yet been demonstrated on a large scale, such as bioenergy with carbon capture and storage. Furthermore, technologies can be excluded from the solution portfolio to provide insights into how much specific technologies influence the feasibility and costs of achieving long-term sustainability targets.

Economic barriers

Costs clearly represent an important economic barrier. IAMs can take into account cost barriers by capping the carbon price at a specified level, thereby allowing only measures that reduce emissions below a certain cost level (megatonnes of CO_2 reduced per US dollar). Cost calculations are also an important output of IAM scenarios, providing direct insight into this barrier.

Rebound effects are especially taken into account by computable general equilibrium models. Potentially important rebound effects are linked to the outsourcing of economic activities (carbon leakage), increasing energy demand due to efficiency gains, and decreasing energy prices due to lower energy demand. Carbon leakage is mainly an issue when there are strong regional differences in the stringency of climate policies, although its effect should not be overstated. Likewise, existing literature does not support claims that energy efficiency gains will be reversed by the rebound effect (Gillingham et al., 2016). However, the rebound effect resulting from lower energy prices due to lower energy demand could be more important (Brink et al., 2013).

Societal barriers

Societal preferences can form important barriers. For instance, the expansion of renewable energy is often influenced by popular attitudes towards these technologies. Such preferences can be introduced in models by including a 'mark-up' rate, that is, by making technologies more expensive. For example, there is evidence that high-income groups tend to use much less coal than cost optimisation would suggest, because coal is inconvenient to use. To reflect these societal preferences, an additional cost factor could be imposed on coal.

Finally, an important feature of IAMs is that they are able to analyse the interactions between different sustainability goals. Many measures targeted at mitigating climate change have implications for other Sustainable Development Goals (SDGs), such as ending poverty, ending hunger, ensuring healthy lives, water availability for all, energy access for all, and protecting ecosystems. Some climate change mitigation measures can help to achieve other SDGs (for example electrification of car fleets reduces both CO_2 emissions and air pollution), while other measures may make it harder to achieve other SDGs. For example, using biomass to reduce CO_2 emissions can produce trade-offs in other areas because the cultivation of biomass requires water and land. It can therefore hamper efforts to ensure water availability for all, protect ecosystems and end hunger, as increased competition for land may drive up food prices.

6.3 Examples of IAM applications

This section addresses three typical examples of the application of IAMs. It comprises:

- a review of how a new common set of scenarios, the 'Shared Socio-economic Pathways' (SSPs), was constructed;
- a discussion of IPCC transformation pathways, focusing on the insights that climate mitigation scenarios provide;
- a discussion of the Roads from Rio+20 scenarios, illustrating how IAM scenarios can be applied to achieve different sustainability goals simultaneously.

The first two exercises focus primarily on climate policy (although the SSPs will most likely also be used by other assessments). In contrast, the *Roads from Rio+20* study is an example of a broad sustainable development analysis. Finally, Section 6.3.3 provides a brief overview of other IAM-based scenario studies.

6.3.1 RCP and SSP scenarios

Model-based scenarios have always played an important role in climate research and assessment. An important reason is that studying climate change requires a long-term perspective. Scenarios also play a key role in connecting the different disciplines involved in climate research, in particular:

- integrated assessment (mitigation analysis and integrated response strategies);
- the climate modelling community (climate change);
- the impact, adaptation and vulnerability research groups.

The SRES scenarios published in 2000 were the first example of scenarios based on both modelling and scenario narratives (or storylines). Such narratives provide a qualitative, consistent description of how key socio-economic parameters may evolve in the future, which is then elaborated using IAM models.

In 2006, a process was started to develop a new set of scenarios. The new scenarios were needed to address various issues such as the growing interest in mitigation scenarios, the need for more recent base-year data and the specific data needs of state-of-the-art models. The roadmap for the new scenario process was described by Moss et al. (2010). The process consisted of three phases:

- In the first step, the IAM community developed a set of pathways for the main driving forces of climate

Table 6.1 Initial starting points for SSP narratives

SSP	Challenges	Illustrative starting points for narratives	Possible SRES analogue
SSP1 (Sustainable development)	Low for mitigation and adaptation	Sustainable development proceeds at a reasonably high pace, inequalities are lessened, technological change is rapid and directed towards environmentally friendly processes, including lower carbon energy sources and high productivity of land.	B1, A1T
SSP2 (Middle of the road)	Moderate	An intermediate case between SSP1 and SSP3.	
SSP3 (Regional rivalry)	High for mitigation and adaptation	Unmitigated emissions are high due to moderate economic growth, a rapidly growing population and slow technological change in the energy sector, making mitigation difficult. Investments in human capital are low, inequality is high, a regionalised world leads to reduced trade flows and institutional development is unfavourable, leaving large numbers of people vulnerable to climate change and many parts of the world with low adaptive capacity.	A2
SSP4 (Inequality)	High for adaptation, low for mitigation	A mixed world, with relatively rapid technological development in low-carbon energy sources in key emitting regions, leading to relatively large mitigative capacity in places where it matters most to global emissions. However, in other regions development proceeds slowly, inequality remains high and economies are relatively isolated, leaving these regions highly vulnerable to climate change with limited adaptive capacity.	No analogue
SSP5 (Fossil-fuelled development)	High for mitigation, low for adaptation	In the absence of climate policies, energy demand is high and most of this demand is met with carbon-based fuels. Investments in alternative energy technologies are low, and there are few readily available options for mitigation. Nonetheless, economic development is relatively rapid and itself is driven by high investments in human capital. Improved human capital also produces a more equitable distribution of resources, stronger institutions and slower population growth, leading to a less vulnerable world better able to adapt to climate impacts.	A1 FI

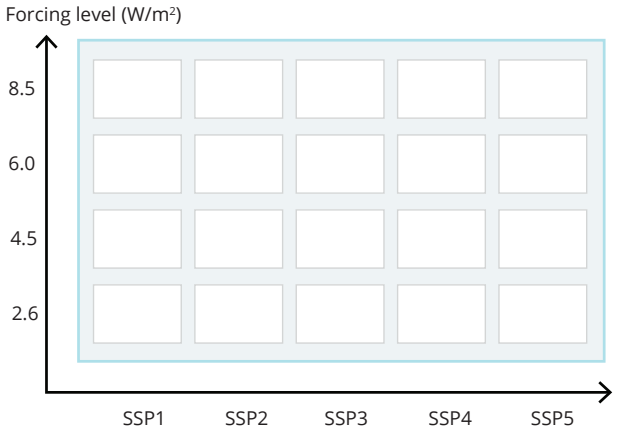
Source: O'Neill et al., 2014.

change, which could be used by the Earth system modelling community to project the magnitude and extent of climate change (Taylor et al., 2012; van Vuuren et al., 2011). These four 'representative concentration pathways' (RCPs) combine pathways for emissions and concentrations of greenhouse gases and air pollutants. One RCP leads to a level of climate change in 2100 consistent with the high end of the literature range (RCP8.5). Two 'stabilisation scenarios' are consistent with baseline development or (very) weak climate policies (RCP6 and RCP4.5). The fourth RCP is consistent with the application of stringent policies to limit emissions (RCP2.6).

- In the second phase, a set of new socio-economic reference scenarios (SSPs) were developed, each with specific challenges for adaptation and mitigation. The SSPs describe five possible futures for socio-economic developments such as population growth, urbanisation, economic development, technology change, lifestyle and, as a consequence, also future energy and land use (Figure 6.6).

- In the third phase, the socio-economic information of the SSPs were combined with the RCPs to provide integrated stories that bring together socio-economic development and the extent of climate change resulting from baseline trends and/or specific climate policies. Each combination of SSP and RCP results in specific challenges with respect to mitigation, adaptation and impacts.

Figure 6.6 The SSP-RCP matrix architecture



Note: The vertical axis of the matrix represents the level of radiative forcing as characterised by the RCPs (radiative forcing is a measure of energy added to world's climate system by greenhouse gases). The horizontal axis comprises a set of alternative plausible trajectories for future global development (the SSPs). The SSPs themselves result in a baseline forcing ranging from just below 6 W/m² to 8.5 W/m², depending on the SSP. Achieving the lower forcing levels in each column requires mitigation strategies and policies addressing greenhouse gas emissions and concentrations and land use change.

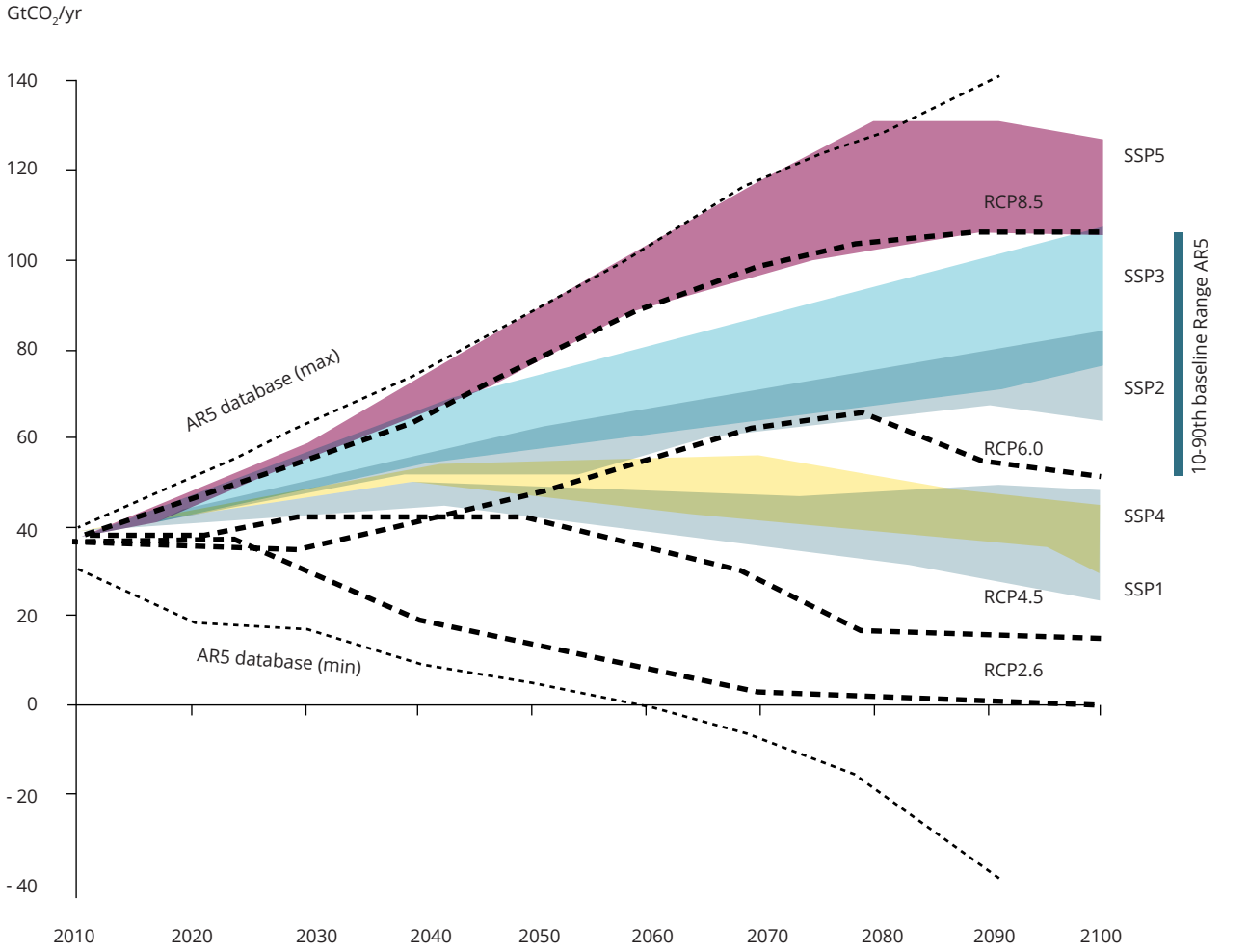
Source: van Vuuren et al., 2014.

The combination of SSPs and RCPs in phase 3 aims to bring together pathways of future radiative forcing and associated climate changes with pathways of socio-economic development. The set of possible combinations is referred to as the matrix architecture (Figure 6.6). The SSPs should be regarded as reference pathways describing plausible alternative trends in the evolution of society and ecosystems over a timescale of a century, in the absence of climate change or climate policies, while the RCPs provide various pathways (for emissions, concentrations and land use change) resulting in different levels of climate change. This matrix helps address key questions related to current climate research and policymaking. These include identifying the effectiveness of different adaptation and mitigation strategies (in terms of their costs, risks and other consequences) and the possible trade-offs and synergies.

A recent article, published in *Global Environmental Change*, provides the first elaboration of the energy, land use and emissions trajectories of SSP-based scenarios (Riahi et al., 2016). The study employed a multi-model approach. Figure 6.7 shows the baseline emission results of the SSPs (i.e. without climate policy) for all the IAMs used, as well as the emission pathways of the RCPs. The SSP baselines show a considerable range of possible emission trajectories but none results in emissions low enough to reach the 2 °C target (which corresponds roughly to the RCP2.6 forcing level). To achieve that target, climate policies need to be introduced in the scenarios. Using the SSP-RCP matrix framework, this implies identifying policy measures that can reduce forcing levels to 2.6 or below (the cells in the bottom row of Figure 6.6). It should be noted that the low forcing levels cannot be reached from all SSPs. For instance, many models cannot reach the 2.6 W/m² level from the SSP3 storyline.

Figure 6.8 illustrates the power-system dynamics underlying several of the emission trends presented in Figure 6.7, based on one specific IAM (IMAGE — Integrated Model to Assess the Global Environment) (van Vuuren et al., 2016). The uncertainty ranges indicate the results of the full set of IAM scenarios. Figure 6.8 shows the results for SSPs 1, 2 and 3. Globally, most electricity is currently produced from coal, followed by natural gas, hydropower and nuclear power. In the SSP1 scenario, electricity use is projected to grow rapidly, which requires a rapid scaling-up of production capacity, mainly based on natural gas and renewables. Interestingly, the 2050 power production in SSP1 exceeds

Figure 6.7 Emission trajectories of CO_2 in the SSP baseline scenarios (coloured ranges) and the RCPs (dashed lines)



Note: The RCPs (dashed lines) represent possible emission trajectories varying from high emissions (RCP8.5) to emissions consistent with ambitious climate policy scenarios (RCP2.6). 'AR5' refers to the IPCC's Fifth Assessment Report. A variety of models was used to assess emissions associated with the five SSPs (coloured ranges). The AR5 database contours indicate the highest and lowest scenarios included in the scenario database compiled for AR5. The shaded areas indicate the 10th-90th percentile ranges for all the scenario results included in the AR5 analysis. All scenarios were created using IAMs.

Source: Riahi et al., 2016.

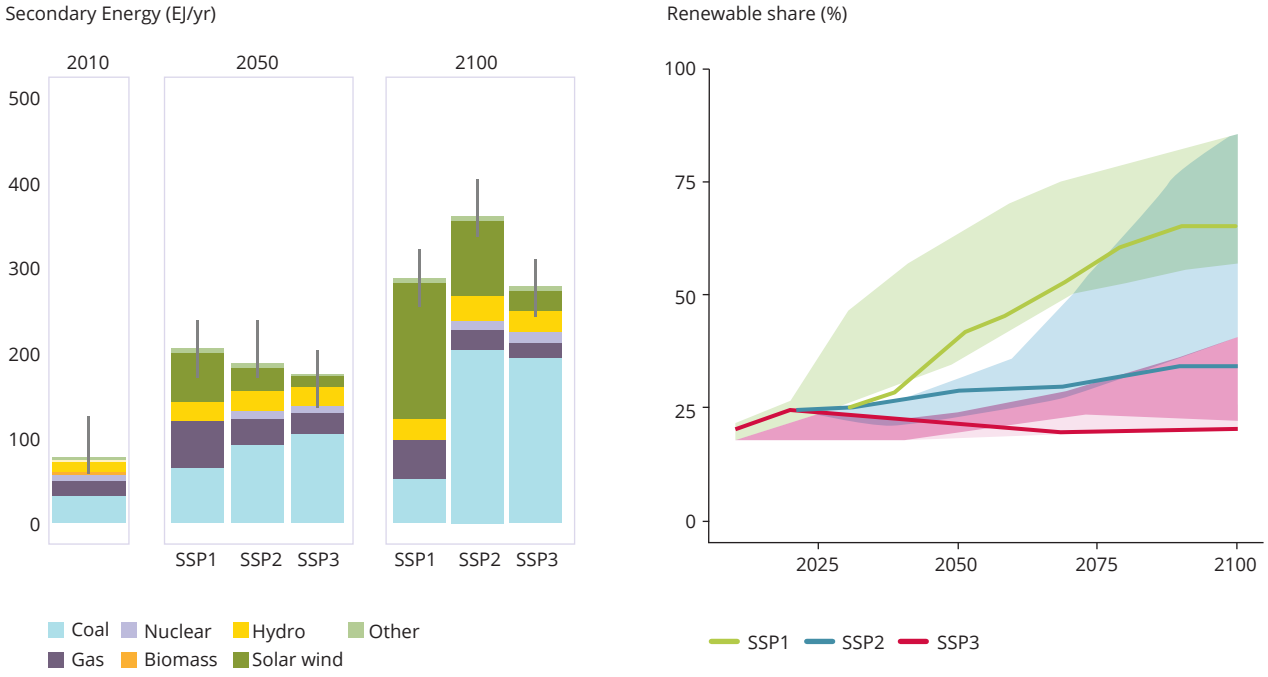
that of SSP2 and SSP3 as a result of the increasing importance of electricity in SSP1 in energy consumption in transport, industry and buildings sectors. In 2100, the majority of power in SSP1 is projected to be produced by renewable energy sources (65 %).

In SSP2, the introduction of renewable energy is much less rapid, accounting for 30 % of power production in 2050 and 40 % in 2100. Here, the additional costs of implementing intermittent renewables remain a significant barrier. This challenge is even more pronounced in SSP3 as a result of slow technological development.

These power-system dynamics are derived from the baseline scenarios for each of the SSPs. Introducing climate policies into the baseline SSPs would increase the contribution of renewable energy.

In the latest IPCC Working Group III report, data from over 1 000 new scenarios published since AR4 were collected from integrated modelling research groups, many from large-scale model inter-comparison studies, to support an assessment of transformation pathways. The assessment was motivated by three questions (Clarke et al., 2014):

Figure 6.8 **Power system development and proportion of renewable energy (showing IMAGE results and other IAMs for comparison)**



Note: The vertical lines and shaded area indicate the range of results of the full set of IAM scenarios for the specific SSP.

Source: van Vuuren et al., 2016.

1. What near-term and future choices define transformation pathways? For example, such choices could relate to the goal itself, the emissions pathway to the goal, the mitigation technologies used, sectors contributing to mitigation, the nature of international coordination and mitigation policies.

2. What are the key characteristics of different transformation pathways? Such characteristics could include the rates of emissions reduction and deployment of low-carbon energy, the magnitude and timing of aggregate economic costs, and the implications for other policy objectives such as those generally associated with sustainable development.

3. How will actions taken today influence the options that might be available in the future?

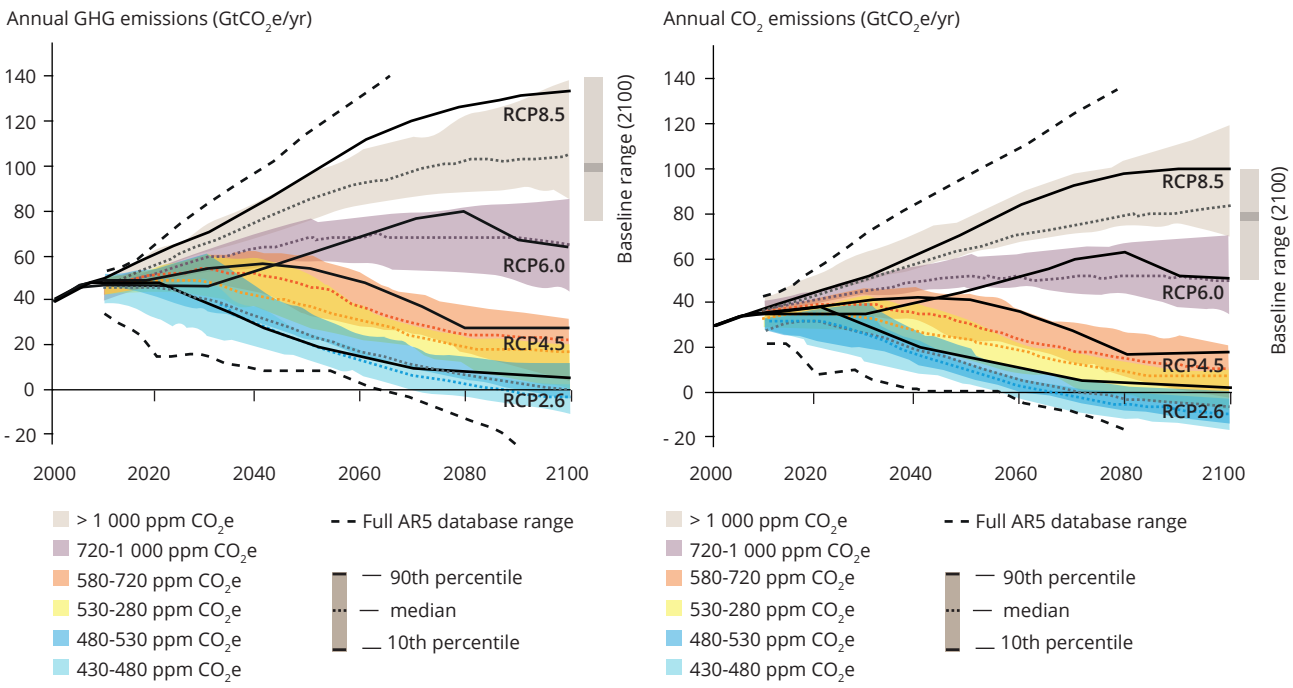
An important conclusion of this assessment was that the models indicate that it will be very hard to limit the global atmospheric concentration of greenhouse gases to 450 ppm CO_2e in 2100 without employing negative emissions techniques. Such techniques include, for example, BECCS and afforestation.

As shown by Figure 6.9, many of the scenarios in the lowest concentration category show net negative CO_2 emissions by the end of the century, implying that technologies that create negative emissions are crucial in current 2 °C scenarios.

6.3.2 Roads from Rio+20 scenarios

In the run-up to the United Nations Conference on Sustainable Development in 2012 (Rio+20), an IAM study was conducted that analysed possible pathways to achieve a set of global sustainability goals for 2050 as an input for the conference (van Vuuren and Kok, 2012; van Vuuren et al., 2015). The goals were derived from international agreements such as the UN Framework Convention on Climate Change (UNFCCC) and the Convention on Biodiversity (CBD). The focus was on eradicating hunger and maintaining a stable and sufficient food production while conserving biodiversity, and ensuring access to modern energy sources for all while limiting global climate change and air pollution. The study used a backcasting approach with the integrated assessment model IMAGE.

Figure 6.9 Greenhouse gas and CO_2 emissions pathways for various concentration categories



Note: The shaded bands indicate the 10th-90th percentile range of results from scenarios used in the study.

Source: Clarke et al., 2014.

Three alternative pathways that combined different assumptions on technology use and consumption changes were used to explore how the 2050 sustainability goals could be achieved:

1. 'Global technology' achieves the 2050 sustainability goals through a focus on large-scale technologically optimal solutions, such as intensive agriculture and a high level of international coordination, for instance though trade liberalisation;

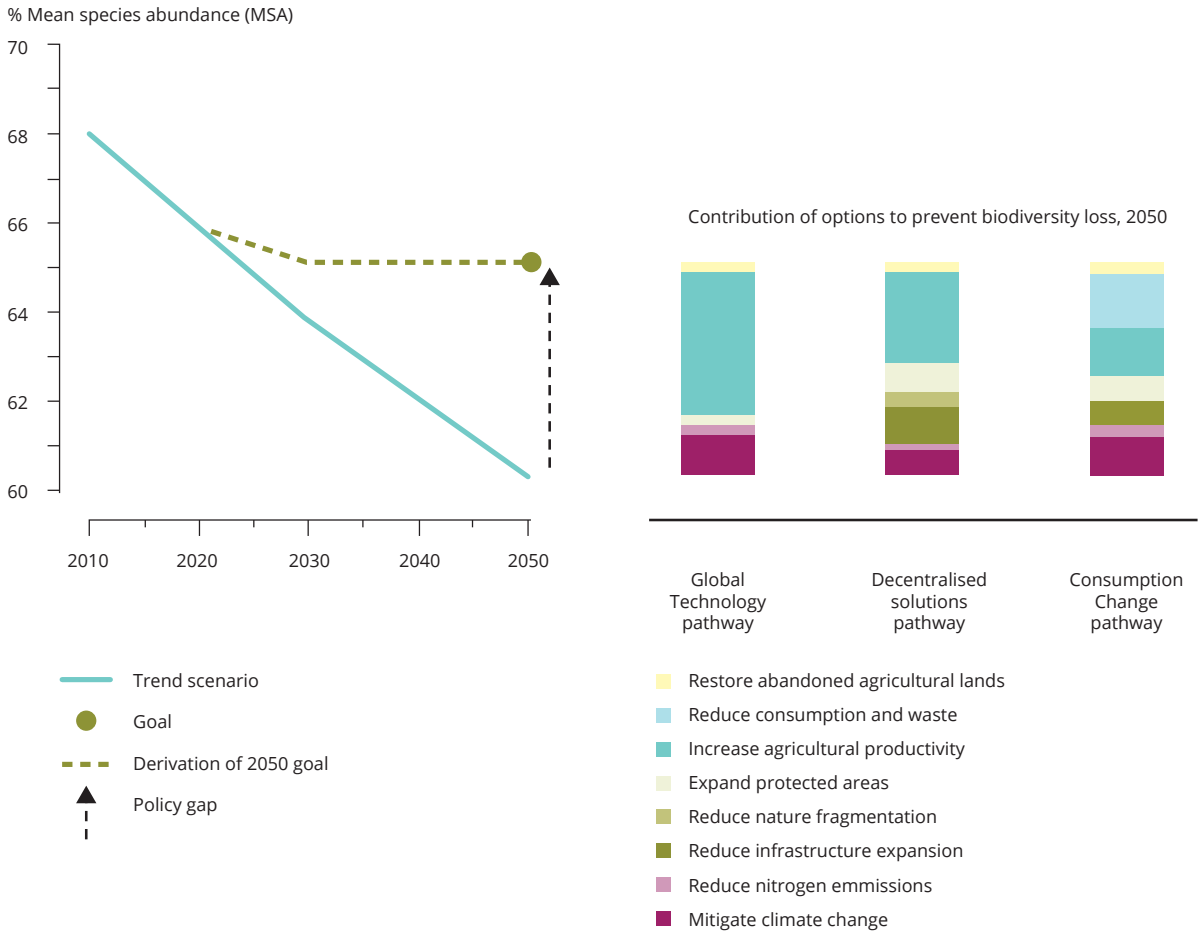
2. 'Decentralised solutions' achieves the 2050 sustainability goals through a focus on decentralised solutions, such as local energy production, agriculture interwoven with natural corridors and national policies regulating equitable access to food;

3. 'Consumption change' achieves the 2050 sustainability goals through a focus on changes in human consumption patterns. Key changes include limiting meat intake per capita, ambitious efforts to reduce waste in the agricultural production chain and adopting less energy-intensive lifestyles.

One key conclusion regarding food, land use and biodiversity was that each of these pathways could prevent over half of the projected future biodiversity loss and would stabilise the extent of natural areas. However, the pathways differ fundamentally in their approach (Figure 6.10). Under the 'global technology' pathway the most important contribution by far comes from increasing agricultural productivity on highly productive land. Under the 'consumption change' pathway, significant reduction in consumption of meat and eggs, and decreased wastage lessens the need for agricultural production, thereby reducing the associated biodiversity loss. Under the 'decentralised solutions' pathway, a major contribution would come from avoided fragmentation, more ecological farming and reduced infrastructure expansion.

Under all scenarios, climate change mitigation, the expansion of protected areas and the recovery of abandoned lands also significantly contribute to reducing biodiversity loss.

Figure 6.10 Global biodiversity and options to prevent biodiversity loss



Source: van Vuuren and Kok (2012).

Table 6.2 Examples of IAM-based scenario rules

Study	IAMs involved	Main focus
Air pollution assessments as part of UNECE, ongoing	RAINS and GAINS models	Cost-effectiveness analysis of European air pollution policies
Millennium Ecosystem Assessment, 2005	IMAGE, AIM, IMPACT (food model)	Explorative scenarios addressing possible changes in ecosystem services (climate, land use)
Global Energy Assessment, 2012	MESSAGE, IMAGE	Integrated energy scenarios
Energy Modelling Forum, ongoing	Many models	Energy and climate policy topics
AMPERE, LIMITS, ADVANCE (FP7 studies)	Several including MESSAGE, REMIND, WITCH and IMAGE	Energy, climate and land topics

6.3.3 Other scenario studies using IAMs

Table 6.2 provides a number of other examples of IAM-based scenario studies, illustrating the range of thematic focuses that have been addressed.

6.4 Governance

In general, IAMs are most suitable to analyse the natural sciences, and technical and economic factors because these disciplines are amenable to the type of generalisation required in such models. Societal dynamics and interactions (e.g. social responses to policies), human behaviour and important social science concepts such as power, agency and learning have proven to be much more difficult to capture in mathematical equations and therefore in IAMs (Biermann et al., 2011).

As a result of these constraints, governance is not explicitly addressed in most IAMs. Nevertheless, there are many ways in which IAM tools are relevant for governance, in particular global governance. The remainder of this chapter address four typical applications of IAMs and their implications for governance: the default use of IAMs to analyse the 'first-best world'; including second-best elements in IAMs; using storylines; and including governance-related factors in models.

6.4.1 Default use of IAMs: the first-best world

To simplify the complexities of the real word and for transparency, model applications often focus on identifying 'ideal' responses to environmental problems. Within the context of many models, this means that the models are used to identify cost-optimal strategies to reach particular objectives by implementing additional 'costs' for activities inconsistent with the objectives within frictionless markets. The objectives can either be calculated by the model (for instance cost-benefit IAMs can calculate the optimal balance within the model between mitigation, adaptation and impacts), or can be based on targets set by the international community (such as the 2 °C target). The 'costs' included in the models are not necessarily meant to be a policy instrument (a tax) but simply ensure that a cost-optimal solution is achieved.

This means that in these models the analysis focuses on economic and technological factors in a stylised manner, neglecting societal dynamics, politics, power and unpredictable human behaviour. Although the assumptions of these 'first-best worlds' do not reflect real-world situations, the outcomes of analyses are still very relevant for policymaking because they provide a benchmark for policies. Even if optimal solutions are difficult or even impossible to obtain due to market and other imperfections, insights about what optimal solutions could look like provide a strong basis for policymaking.

For example, IAMs provide insights about the feasibility of achieving long-term climate targets, important technology portfolios and corresponding first-order estimates of costs. Several IAM studies have shown the importance of energy efficiency, carbon capture and storage, and bio-energy in the technology portfolio (e.g. van Vuuren et al., 2007; Clarke et al., 2010; Edenhofer et al., 2010; Kriegler et al., 2014a; Rogelj et al., 2015). IAM studies also provide important insights about the 'optimal' timing of climate policy, in particular about 2020 and 2030 emission levels in relation to long-term climate objectives (Rogelj et al., 2013; van Vuuren and Riahi, 2011; Wigley et al., 1996).

6.4.2 Including second-best elements in IAMs

IAMs have also been applied under different 'second-best' assumptions to assess the consequences of such imperfections. These applications do not differ fundamentally from the default use of IAMs, but do provide some additional insights for governance.

Important second-best elements studied by IAMs include delayed participation of certain countries in climate agreements and burden-sharing approaches. Prime examples of this approach are the studies by Clarke et al. (2009) and Kriegler et al. (2014b), in which the impact of limited participation of regions in international climate policy was analysed using a multi-model comparison exercise. One key outcome was that increasing participation is essential for climate policy to succeed.

Several studies also looked at different assumptions regarding burden-sharing arrangements and the extent of participation. Hof et al. (2009) provide a comprehensive overview of these studies, showing that the allocation of costs to different world regions depends significantly on burden-sharing assumptions, and that the total costs of achieving climate targets increases significantly under a fragmented climate policy regime (as opposed to a single global regime with universal participation).

Another important second-best element studied by IAMs relates to restrictions on the implementation of mitigation technologies. The potential role of different technologies is uncertain and depends on their future development and overall potential but also on societal

choices based on judgements about their impacts and risks. These issues are especially important for technologies such as nuclear power, carbon capture and storage and bio-energy. Several studies have looked at the impact of technological availability on costs and on the feasibility of achieving greenhouse gas targets (Kriegler et al., 2014c; van Vliet et al., 2014), providing indications about the importance of technologies in achieving long-term climate targets.

Finally, IAMs have assessed the consequences of delays in short-term climate mitigation action. Several studies have shown that optimal 2 °C target emission pathways (as calculated by first-best world assumptions) imply emission levels in 2020 and 2030 that are lower than the levels currently pledged by countries (UNEP, 2015). IAMs have been applied to assess the consequences of such delays in climate mitigation action, in terms of both costs and the feasibility of achieving long-term targets (den Elzen et al., 2010; Luderer et al., 2016; Riahi et al., 2015; van Vliet et al., 2012).

6.4.3 Storyline-based scenario assumptions

A further method to incorporate factors that are difficult to capture in mathematical models (such as governance-related factors) is to develop scenarios on storyline-based assumptions. However, the use of this approach is still rather limited.

The IPCC's SRES provides an early example in which explicit storylines were developed (Nakicenovic and Swart, 2000). The scenarios were developed based on two axes: one ranging between an economic focus and an environmental focus; the other ranging between globalised and regionalised governance responses (Figure 6.11).

These and similar storylines have been used to discuss governance issues in detail in different exercises. For example, van Vuuren et al. (2003) explored baseline and mitigation scenarios for China based on the IPCC storylines and concluded that an orientation towards environmental sustainability could not only reduce environmental pressures but also lower carbon emissions. Another notable example is Cork et al. (2005), who assessed the implications for ecosystem services of four internally consistent scenarios.

For the new IPCC scenarios, governance issues are directly addressed by the concept of Shared Policy Assumptions (Kriegler et al., 2014a). These assumptions describe three attributes of climate policies: goals; policy regimes and measures; and a description of how implementation limits and obstacles are addressed.

The formulation of shared policy assumptions on a global and long-term scale can become complex. However, the goal of shared policy assumptions is not to describe the climate policy landscape in every conceivable detail, but rather to summarise and make explicit the central policy assumptions made by individual studies to produce climate policy scenarios. The method intends to provide a community language on different assumptions going from the previous set of 'first-best' worlds to more comprehensive assumptions, including a more explicit treatment of governance and institutional dimensions in scenarios. *The Roads from Rio+20* study (discussed in Section 6.3) provides an example of this approach.

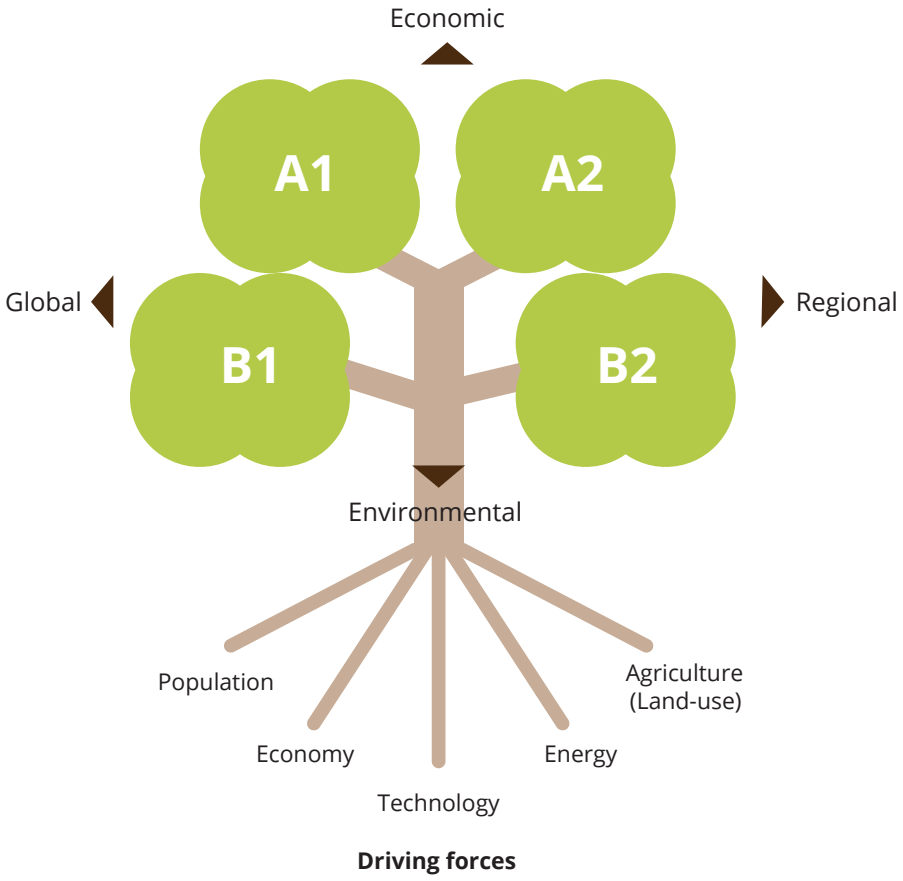
Another way to focus on policies more explicitly in model-based scenarios is to start from specific measures. Examples include recent scenarios by the International Energy Agency (IEA, 2013) and the work of Deetman et al. (Deetman et al., 2013, 2015). The IEA has looked into the impact of a limited set of measures that could, based on an assessment of the current policy situation, be implemented in the next 10 years. The study introduces these measures to show a trajectory that would be modest up to 2025, but that would still allow the 2 °C target to be achieved. The Deetman studies used a similar approach by looking into the impact of measures often mentioned in current climate politics debates, exploring which combination of these measures would be sufficient to achieve the 2 °C target.

6.4.4 Including governance-related factors in models

A final approach is to build governance-related factors explicitly into models. Agent-based models are, again, a prime example. The strength of these models is that they can directly relate to the interest of individuals or individual actors such as companies. Such models tend to focus on scientific questions of system behaviour and are used less frequently to provide direct policy advice. However, some agent-based models are directed at analysing real-world policies, such as for the European transport system (Schade, 2010). Another example is the PRIDE model (Kalkuhl et al., 2015), which explicitly represents different economic agents (households, producers, fossil fuel and renewable energy firms, and fossil fuel resource owners), as well as policy instruments in an IAM.

Staub-Kaminski et al. (2014) introduce this approach as 'integrated policy assessment models' (IPAMs), but also identify associated difficulties. Still, they argue in favour of combining IAMs with more stylised models that capture specific imperfections to estimate the impact of specific barriers on model results.

Figure 6.11 Schematic illustration of the SRES scenarios



Source: IPCC, 2000.

Starting from regime theory in political science, an attempt was made to formalise knowledge on the effectiveness of environmental regimes by including it in IAMs (Biermann et al., 2011). A conceptual framework for the systematic analysis of conditions that influence regime effectiveness was constructed and implemented in a computer model using fuzzy logic methodology. The authors concluded that at this stage it is not yet possible, and is even undesirable, to include knowledge on environmental regimes directly in IAMs. The scope and variables differ too much from those used in IAMs to bridge the gap in a direct way and enable successful and meaningful integration. Instead, conceptual models could enhance the interpretation of results from IAMs by examining the political context more explicitly. A similar conclusion was recently reached by Geels et al. (2016b).

6.5 Strengths and weaknesses of IAMs

6.5.1 Strengths

IAMs are well established in academic literature. Results of IAM exercises are widely published in top peer-reviewed journals, often with a multi-model comparison approach to assess the robustness and uncertainties of the results.

In analytical terms, a general strength of IAMs is their internal consistency across a wide range of issues related to global environmental change, taking into account system interdependencies. Other models that explore environmental issues, such as life-cycle assessment models, Earth system models and bottom-up models, do not take into account important

feedback within key systems (such as the energy system) and more importantly, between human and environmental systems. IAMs are therefore very useful to explore key long-term dynamics and highlight interactions and trade-offs. By aggregating analysis of many measures, IAMs can provide insights into whether different measures overlap or strengthen each other.

The focus on quantitative analysis provides policymakers with concrete results on how policy objectives relate to required physical (climate, biodiversity, land use) changes. IAMs are able to calculate quantitative effects of different policy options, thereby providing insight on how policies can influence transition pathways. Indeed, it is notable that IAM results are among the scientific outputs used most frequently by policymakers. This is perhaps partly because quantitative IAM results offer apparently clear answers to complex questions, which can aid communication and uptake. Moreover, IAM results align with the data and indicators that make up much of the knowledge base supporting environmental policy, and can be translated easily into targets and objectives. The popularity of IAMs is apparent in their use in EU policy (for example impact assessments of EU directives often refer to IAM results) and in international assessments such as those of the IPCC and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

Setting long-term targets and highlighting short-term priorities

IAMs have generated a considerable evidence base of forward-looking projections and scenarios, which have been influential in informing high-level policymaking, both in an agenda-setting role and for establishing long-term targets. For example, the EU Roadmap for moving to a low-carbon economy in 2050 is strongly based on IAM results. It provides that 'The transition towards a competitive low carbon economy means that the EU should prepare for reductions in its domestic emissions by 80 % by 2050 compared to 1990. The Commission has carried out an extensive modelling analysis with several possible scenarios showing how this could be done.' (EC, 2011b).

IAMs provide several indictors that can support long-term target setting. The most obvious is the level of reduction of CO_2 or greenhouse gas emissions needed in a specific year to achieve a specified climate target with a certain probability. For example, in its authoritative annual emission gap report, UNEP assesses the results of IAM results to provide an emission range for the years 2020 and 2030 that is in line with achieving a 2 °C and 1.5 °C target with likely probability (UNEP, 2015). It concludes that the global emission level should be in the range of 31-44 Gt CO_2e by 2030 for a likely probability of achieving the 2 °C target.

The IPCC Fifth Assessment Report Working Group III report also provides estimates of the available carbon budget for achieving climate targets (Table 6.3 of Clarke et al., 2014), and concludes that cumulative CO_2 emissions need to be between 630 and 1180 Gt CO_2e to achieve the 2 °C target with likely probability.

Another important indicator for target setting includes the year in which global or regional emissions need to peak to remain within a 2 °C or 1.5 °C pathway. For instance, Clarke et al. (2014) concluded that for a likely probability of achieving the 2 °C target, emissions need to peak in 2010 in OECD countries, between 2015 and 2030 in Asia, between 2010 and 2020 in Latin America, between 2010 and 2030 in the Middle East and Northern Africa region, and between 2010 and 2015 in economies in transition.

Similar to this, IAMs provide insight into the effect of delaying mitigation action — either globally or regionally — on the costs and feasibility of achieving long-term climate targets (Kriegler et al., 2014b; van Vliet et al., 2012). For instance, van Vliet et al. concluded that there is limited flexibility in 2020 emission levels if the 2 °C climate target is to be achieved. The 2020 emission level represents a trade-off between short-term emission reductions and long-term dependence on rapid reductions through specific technologies (such as negative emission reductions). Higher 2020 emissions lead to higher overall costs and reduced long-term flexibility, both leading to a higher risk of failing to hold global warming below 2 °C.

Modelling outcomes can also serve to assess policy promises in terms of the technological effort, economic cost, distribution of costs and benefits, and trade-offs between different options. In terms of technological effort, IAMs provide information on the importance of different technologies in achieving long-term climate targets by several multi-model comparison exercises. The most important indicator used for this is the change in costs of achieving long-term climate targets when certain technologies are unavailable or are only available to a limited extent. It has been shown, for instance, that without carbon capture and storage as a mitigation option, the costs of achieving ambitious climate targets increase dramatically, or targets become unachievable (Kriegler et al., 2014c; van Vliet et al., 2014).

Finally, IAMs provide insights on differences in mitigation costs between regions, which provides important input for discussions about equity. An IAM literature review by Hof et al. (2009) showed that, for instance, global carbon tax costs tend to be higher in developing countries because the burdens of a tax regime are carried mostly by those regions with high carbon intensity or with substantial opportunities to reduce emissions.

6.5.2 Weaknesses

Although the ease with which quantitative results can be communicated and taken up in policy is certainly a strength of integrated assessment modelling, it is also a potentially important weakness. Futures are inherently uncertain and, although IAM developers acknowledge the role of uncertainty (e.g. by emphasising that IAMs are about 'insights' and not about 'numbers'), such caveats are often overlooked when IAM results are transposed into policies. For example, emission reduction targets are often directly based on quantitative IAM results, using the numeric results without interpreting the conditions on which the results are based.

The focus of IAMs on long-term processes may also mean that IAMs are less suitable for analysing short-term aspects of transitions. In these cases, methods that rely more on statistical analysis and data are often more appropriate. Such methods include computable general equilibrium models, life-cycle assessment models and bottom-up analysis.

IAMs typically conceptualise systems as collections of technologies and their interactions, and understand transitions as changes in consumption and production patterns, technologies and resources. This means that many IAMs often neglect the role of organisational, social and business model innovations in low-carbon transitions. IAMs also tend to overlook less tangible aspects of transitions, such as the institutional and cultural context of social and technological innovation, the role of power and legitimacy and the non-linearity (and non-rationality) of real-world processes.

The intent to simplify decisions in terms of cost-optimisation mostly steered by price incentives is consistent with mainstream economic theory, but often leads to restrictive assumptions about the behaviour of social actors, for example, including rational decision-making and competitive price-taking behaviour (with no monopolies or strategic behaviour present).

Although there are some exceptions, IAMs generally represent policies in terms of a uniform carbon tax, neglecting issues related to policy implementation of other policy instruments. Also, the default IAM assumption of an 'ideal world' (again motivated by transparency) downplays some governance issues, such as strategic behaviour and including resistance to change from powerful social and business interests. For instance, policymakers are usually constrained by their dependence on other actors (such as firms, electorates and civil society) for skills, financial resources, deployment and legitimacy.

As IAMs integrate different human and physical systems, the models are generally quite complex, which decreases their transparency. Recent efforts, notably in the EU FP7 ADVANCE project (ADVANCE, 2017), make a coordinated effort to improve model transparency, model validation and data handling.

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