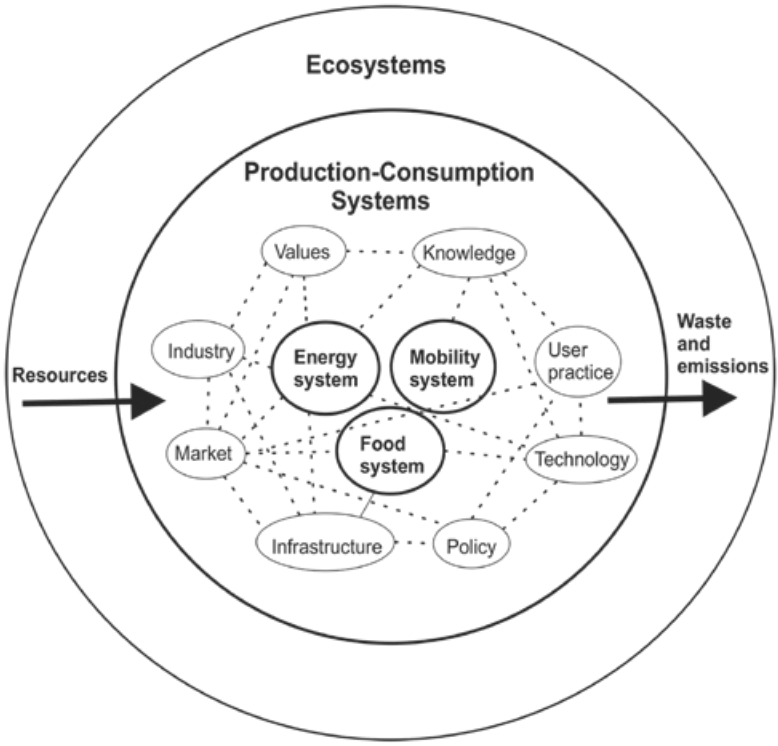
1 Introduction to sustainability transitions

1.1 The need for sustainability transitions

Recent assessments from the Intergovernmental Panel on Climate Change (IPCC, 2022), the European Environment Agency (EEA, 2019), the United Nations Environment Programme's International Resource Panel (UNEP IRP, 2019) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, 2019) show that problems such as climate change, biodiversity loss, and resource scarcity are continuing to worsen, creating increasing pressures on natural ecosystems and causing negative impacts on society through heatwaves, fires, droughts, floods, and crop failures.

To mitigate these problems, these organisations increasingly call for sustainability transitions in energy, food, mobility, and other systems to reduce the use of resources and the emission of wastes, pollutants, and gases, including greenhouse gases (Figure 1.1). The IPCC (2018, p. 21), for instance, calls for 'rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems. These systems transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emission reductions in all sectors'. To keep climate change 'well below' 2°C, the UNEP (2022, p. xxii) similarly concludes that 'wide-ranging, large-scale, rapid and systemic transformation is now essential'.

Besides the focus on systems, another important dimension of sustainability transitions is the speed of change. Because environmental problems continue to worsen, it is essential to increase the speed of sustainability transitions, with many reports seeing the 2020s as the crucial decade. The latest assessment by the IPCC, for example, concludes that '[t]he 2020–2030 decade is critical for accelerating the learning of know-how, building the technical and institutional capacity, setting the appropriate



Source: Adapted from EEA (2019, p. 345).

Figure 1.1 Production-consumption systems in the context of natural ecosystems

governance structures, ensuring the flow of finance, and in developing the skills needed to fully capture the mitigation potential of buildings' (IPCC, 2022, p. 31). Along similar lines, the UNEP warns that the window of opportunity for keeping climate change below 2°C is closing and that 'increased and accelerated action is needed' (UNEP, 2022, p. xxii).

On the positive side, many radical innovations (which are defined as significantly deviating from existing systems on one or more dimensions) with high sustainability potential have emerged in the past few decades, which could form the building blocks of sustainability transitions. Table 1.1 provides a selective overview of relevant technical, social, business

model, and infrastructural innovations across three important systems. Some of these innovations have already started to diffuse rapidly in many parts of the world – notably, wind turbines, solar PV, and electric vehicles (EVs). On the negative side, many other sustainability innovations are still confined to research and development (R&D) projects or small market niches, and are not (yet) diffusing at sufficient speed and scale (International Energy Agency [IEA], 2023a; IPCC, 2022). This book will provide analytical tools that can explain both the acceleration of some sustainability innovations and the limited progress of others.

1.2 Situating sustainability transitions in the wider literature

To better understand sustainability transitions and large-scale transformations, different research communities have emerged in the past two decades. While this has deepened our understanding in some respects, it has also created some degree of conceptual and terminological confusion because these communities have different disciplinary backgrounds, focus on different kinds of systems, and have different goals. Drawing on other typologies (Feola, 2015; Geels, 2019; Loorbach, Frantzeskaki and Avelino, 2017; Patterson et al., 2017), this section therefore briefly positions the sustainability transitions approach, which is the focus of this book, in relation to three other approaches.

The sustainability transitions approach focuses on major changes in production-consumption systems (Figure 1.1), which combine heterogeneous elements to meet specific human needs and fulfil societal functions such as food, shelter, energy, mobility, and health (Geels et al., 2015; Geels, Kern and Clark, 2023). The approach sees innovations as central building blocks for sustainability transitions (Table 1.1) but also emphasises that their development and diffusion crucially depend on the business, social, political, and cultural contexts in specific systems. Because of this innovation-in-context focus, the approach originally mobilised concepts from evolutionary economics, the sociology of innovation, and institutional theory (Fuenfschilling and Truffer, 2014; Geels, 2004, 2020). Later, it also incorporated insights from the wider social sciences to understand processes of change, as this book will show.

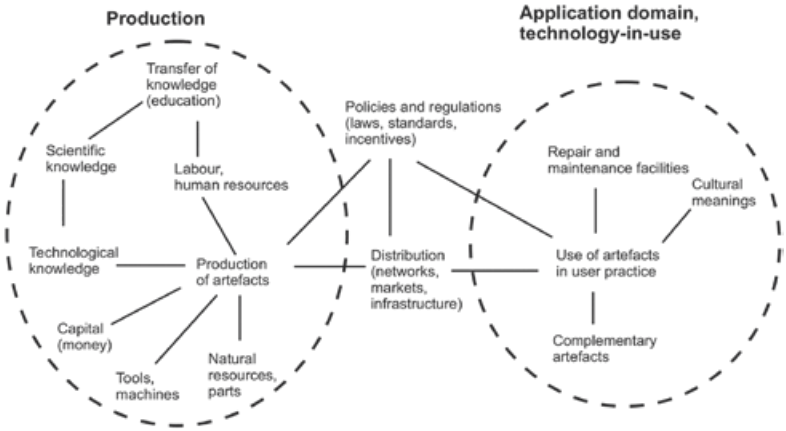
The approach conceptualises production-consumption systems as socio-technical systems (Figure 1.2) because this helps to overcome the unhelpful dichotomy in sustainability debates between technological

Table 1.1 Examples of innovations to promote sustainability (with varying transformative potential) in mobility, agrifood, and energy systems

	Mobility system	Agrifood system	Energy system (electricity, heat)
Radical technical innovation	Battery electric vehicles (BEVs), (plug-in) hybrid electric vehicles (PHEVs), biofuel cars, hydrogen fuel cell vehicles	Permaculture, agroecology, artificial meat, plant-based milk, manure digestion	Renewable electricity (wind, solar, biomass, hydro), heat pumps, passive houses, biomass stoves, smart meters
Grassroots and social innovation	Car sharing, bike clubs, modal shift to bicycles and buses, teleworking, teleconferencing	Alternative food networks, less-meat initiatives, veganism, urban farming	Decentralized energy production ('prosumers'), community energy
Business model innovation	Mobility services, car sharing, bike sharing	Alternative food networks, organic food, agroecology	Energy service companies, back-up capacity for electricity provision, vehicle-to-grid electricity provision
Infrastructural innovation	Intermodal transport systems, compact cities, revamped urban transport systems (tram, light rail, metro)	Efficient irrigation systems, agroforestry, multifunctional land use	District heating system, smart grids, biomethane in reconfigured gas grid

Source: Adapted from Geels (2019, p. 190).

solutions and social solutions. It thus understands social and technical elements as always intertwined (Callon, 1987; Latour, 1990; Pinch, 2008). The socio-technical system conceptualisation also acknowledges that modern societies since the late 19th century (when research and development became institutionalised in industrial laboratories) have taken on a quasi-evolutionary dynamic, in which researchers, engineers and firms incessantly generate novelties (or 'variations' in evolutionary terms), which are then exposed to selection pressures from users, policymakers, and wider publics, which shape their wider adoption or rejection (Hughes, 2004; Schot, 1992).



Source: Adapted from Geels (2004, p. 900).

Figure 1.2 Schematic representation of socio-technical system elements

The sustainability transitions approach has developed a range of concepts, which this book discusses in more detail, to understand the *processes* of change, which are understood as shifts from one socio-technical system to another. Historical examples, which are further described in the next chapter, include the shift in mobility systems from horse-drawn carriages to automobiles (Geels, 2005a) or the shift in water supply systems from pumps and surface water to piped systems that delivered clean water indoors (Geels, 2005b). These transitions involved technological discontinuities as well transformations in cultural meanings, user practices, pol-

icies, and infrastructures. The transitions approach has a strong interest in 'how' questions, using both historical and contemporary case studies to develop an empirically validated theory of change that helps understand and explain transition processes.

Another approach has been developed by the socio-ecological research community (Folke et al., 2005; Olsson, Galaz and Boonstra, 2014; Olsson et al., 2006), which initially emerged in ecology but subsequently incorporated insights and scholars from various social sciences. This approach focuses on socio-ecological systems, which involve interactions between ecosystems and humans at different spatial scales that can range from the entire earth system (Schellnhuber et al., 2005) to localised ecosystems such as particular lakes, forests, or coral reefs. This approach talks more about sustainability transformations than about sustainability transitions because deliberate change is less about replacing one ecosystem with another and more about transforming their management and stewardship to prevent them from collapsing (Chapin et al., 2010). The normative interest is thus arguably opposite to the transitions approach in that the socio-ecological approach focuses on transformations in governance and user practice that *prevent* the existing (eco)system from radically changing (through collapse) by reducing stresses and increasing its resilience (Smith and Stirling, 2010). Conceptualising socio-ecological systems as complex adaptive systems, scholars suggest that adaptive governance involves three key steps: preparing for change, navigating the transition to a new regime, and increasing the resilience of the new regime (Chapin et al., 2010; Olsson et al., 2006, 2014). The socio-ecological system approach draws on a wealth of empirical research and has been conceptually elaborated in many ways (Folke et al., 2021).

A third approach, which goes under labels such as grassroots innovation (Seyfang et al., 2014; Seyfang and Smith, 2007) or sustainability pathways (Leach et al., 2012; Leach, Scoones and Stirling, 2007), suggests that radically new ideas, sustainability innovations, and new lifestyles are pioneered by local communities or activists who then align into social movements that engage in uphill socio-political campaigns to drive changes in formal institutions and cultural views. Sustainability transformations are thus seen as bottom-up processes, driven by vanguard idealists or civil society actors such as social enterprises, schools, faith groups, or community activists. This approach draws inspiration from social movement theory, where empirical studies of civil rights movements or suffragettes

have demonstrated that sustained campaigns from marginalised groups can (eventually) bring about major transformation, often after prolonged political struggles.

With regard to sustainability transitions, however, the empirical evidence of this approach is less convincing. Although there have been many grassroots projects in the past decade (e.g., community energy projects, Transition Town initiatives, ecovillages, community gardening), these have not diffused widely or triggered sustainability transformation at scale (Hossain, 2016, 2018). Steward (2018, p. 100) therefore observes that 'the significance of acting at the local level (often vaguely specified) is largely an article of faith'. Case studies of local grassroots projects are impressive and inspiring, but 'do not demonstrate to academic critics that this is a route for a transition to a low-carbon society at a broader level' (ibid.). One reason for limited upscaling is that the reliance on non-market mechanisms (e.g., voluntary commitments, occasional grants) makes grassroots innovations fragile and difficult to sustain over time. Another reason is that some grassroots innovators do not aspire to scale up because their advocated solutions cater exclusively to a local community (Hossain, 2016). Grassroots activists may also resist mainstreaming if this involves the loss of particular values that inspired initial initiatives. Lastly, high hopes about an upsurge of communitarian activities are rather wishful compared with empirical evidence about the decline of social capital in recent decades (Putnam, 2000).

A fourth approach consists of critical assessments of bigger systems and societal deep structures that are claimed to be the root causes of sustainability problems. Drawing on neo-Marxism or critical political economy (Newell, 2021), some scholars criticise the 'capitalist system' for its focus on profits and economic growth, arguing instead for degrowth and a new economics that 'advocates whole system change on the grounds that global capitalism is an anti-human, unsustainable and dysfunctional system…its focus is on deep economic and social transformation… At its core it references jobs, livelihoods and enterprise, along with other elements of well-being such as stable communities, healthy food systems, vibrant neighborhoods. It locates fairness at its center, arguing for more equitable distributions of wealth and power. It includes climate and eco-systems, but as part of an economic alternative, rather than just an ecological shift' (Schor, 2014, p. 15).

Other scholars in this approach criticise consumer society and its underpinning beliefs and values, which should be transformed in the direction of frugality and sufficiency (Alcott, 2007; Princen, 2005). These scholars often take inspiration from deep ecology (Næss, 1973) or critical systems thinkers (Meadows, 1999) in suggesting that it is fundamental changes in people's values, mindsets, and goals that are the most powerful leverage points in driving sustainability transformations (O'Brien, 2016).

While this approach usefully draws attention to macroeconomic and macro-cultural issues, it is not very useful for empirical analysis because it is too grand, abstract, and distanced from the experiences of real-world actors in particular production-consumption systems. This approach also restricts itself to critiques of deep structures and advancing utopias of desired future societies without offering viable suggestions for how the desired changes could be brought about. The calls for deep transformation thus remain remarkably empty in terms of concrete advice, giving this approach aspirational and 'wishful thinking' characteristics. There is also little empirical evidence for this approach to sustainability transformation. Even when the 2007/08 financial crisis and the 2020 COVID-19 pandemic arguably created windows of opportunities for deep transformative change, including calls for green recoveries and to 'build back better', the results have been disappointing (Barbier, 2010; Geels, Pereira and Pinkse, 2022; UNEP, 2021). Lastly, it does not seem likely or feasible to deeply transform the capitalist system or cultural values in the next few years, which means that this approach is not very relevant with regard to the need for acceleration that was noted above.

Although I am critical of the third and fourth approaches to major transformations, some elements of these approaches have been incorporated in the sustainability transitions approach – notably, the importance of civil society actors, ideas, and cultural discourses, as the book will show. Feola (2015, p. 385) characterised the first two approaches as analytical-descriptive and interested in actual change processes, using 'substantive, non-prescriptive and theoretically-grounded concepts of transformation which identify patterns and units and their relationships'. In contrast, the third and fourth approaches are more normative, prescriptive, less empirically supported, and focused on desired rather than actual change processes.

This book focuses on sustainability transitions research rather than on socio-ecological systems research, because the latter focuses more on ecosystems (and humans) and the former more on production-consumption systems, which are the core driver of many persistent environmental problems. Addressing these problems therefore requires sustainability transitions in these systems. A consequence of the book's focus on the first approach is that it has more to say about the climate change problem than about biodiversity. Although the socio-technical approach to sustainability transitions has been applied to topics that are relevant for ecosystems and biodiversity – including salmon fishing (Gudbrandsdottir et al., 2021); plant-based milk and meat alternatives (Bulah et al., 2023; Dueñas-Ocampo, Eichorst and Newton, 2023; Moritz et al., 2023; Mylan, Andrews and Maye, 2023; Mylan et al., 2019); landscape protection (Barbanente and Grassini, 2022); (agro)forestry (Sergent, 2014; Sorge et al., 2022; Vangansebeke et al., 2015); agroecology (Duru, Therond and Fares, 2015; Elzen et al., 2017); and agrifood systems more generally (Bui et al., 2016; Medaets, Fornazier and Thome, 2020) – it is fair to say that the majority of socio-technical transitions research has focused on climate change and low-carbon transitions. This book therefore does not address biodiversity, ecosystem dynamics or their stewardship in any depth. The socio-ecological system approach arguably has more to offer in that regard.

1.3 Characteristics of sustainability transitions

Having positioned the sustainability transitions approach in relation to other approaches to large-scale change, this section describes some basic characteristics of the phenomenon of sustainability transitions (Köhler et al., 2019). The remainder of the book will then describe and discuss conceptual frameworks and theories that help understand and explain (parts of) this phenomenon.

First, sustainability transitions are about significant changes in *socio-technical systems* (or production-consumption systems). This means they are *multidimensional* processes in which multiple elements (e.g., technology, user practices, public policies, cultural meanings, infrastructures, scientific understandings, industry, supply chains) interact and *co-evolve* (Geels, 2004). To reduce this complexity and enable empir-

ical research, sustainability transitions research often takes innovations as the analytical entrance point and then investigates how these innovations interact with other elements and processes during their emergence, diffusion, and societal embedding (Geels, 2005c).

Second, sustainability transitions are *multi-actor processes* that unfold through the actions and interactions between firms, users, social movement organisations, wider publics, policymakers, industry associations, and other special-interest groups (Geels, 2004). These actors have different goals, interests, beliefs, resources, capabilities, and engage in a wide range of activities that change over time, as the book will show. The relative importance of different actors varies between different systems, giving rise to different kinds of transition patterns (Geels and Turnheim, 2022), and between different countries, depending on wider political, economic, and socio-cultural contexts (Loewen, 2022).

Third, sustainability transitions are *long-term processes* that may take decades to unfold because radical innovations often emerge slowly and because existing systems may be hard to dislodge. Scholars therefore often distinguish different phases such as experimentation, stabilisation, diffusion, and reconfiguration (Geels, 2019), which are characterised by different processes and interactions. Because of the interest in 'how' questions, transition scholars typically focus on the *temporal unfolding* of processes over time, leading to an interest in event chains, moves and countermoves, unintended consequences, learning processes, surprises, struggles, changing coalitions, and changing contexts (Geels, 2022a).

Fourth, sustainability transitions are *goal oriented* because they aim to significantly improve the environmental performance of existing systems, while also being socially and economically sustainable. Many environmental problems are externalities for firms and consumers, which they limitedly consider in their actions. Policymakers are therefore often essential in sustainability transitions to shape the directionality of change through targets, laws, regulations, and financial incentives. While actors may agree on general goals (like 'net zero' for climate mitigation), they often disagree about specific transition pathways. With regard to net-zero electricity generation, for example, actor preferences vary across nuclear power, wind turbines, solar PV, biomass combustion, or coal plants with carbon capture and storage (CCS). Sustainability transitions thus often

involve struggles over preferred innovations, transition pathways, and the shape of future systems (Delina and Janetos, 2018).

Fifth, sustainability transitions are full of *conflict and struggle*. Because they threaten to disrupt the status quo, transitions often face resistance from powerful industries with vested interests in existing systems (e.g., fossil fuel companies, agrifood firms, automakers). But consumers and societal groups may also resist specific changes as recent examples indicate: the French Yellow Vests movement protested against increased fuel taxes, Londoners protested against proposed expansions of the ultra-low emission zone, Dutch farmers and other groups protested against stricter nitrogen regulations, and in Germany there were protests against proposed gas boiler bans. While these social acceptance problems are certainly exacerbated by right-wing populist organisations and politicians (Lockwood and Lockwood, 2022), many groups do have legitimate concerns about costs and livelihoods that can hamper transitions.

Sixth, sustainability transitions are *non-linear*, *uncertain*, and *open-ended* processes. In most systems, there are multiple innovations with high sustainability potential (see Table 1.1), which makes it difficult to predict in advance which ones will prevail. Innovation trajectories are also non-linear (Geels and Raven, 2006; Messner, 2015), as they may experience technical breakthroughs or rapid cost reductions, setbacks, unintended consequences, or social acceptance problems. Struggles, learning processes, shifting coalitions, changing political priorities, or external shocks may also accelerate or derail sustainability transitions, making them challenging processes to navigate (Olsson et al., 2006; Van Mossel, Van Rijnsoever and Hekkert, 2018).

These characteristics make sustainability transitions a special kind of phenomenon that is difficult to address for mainstream social science disciplines, which typically make snapshot analyses of short-term processes (Pierson, 2004) and focus on one particular dimension or actor (e.g., business, politics, users, culture). Sustainability transitions research has therefore increasingly moved towards using a flexible middle-range conceptual framework (the so-called Multi-Level Perspective, MLP) that captures multiple phenomenological characteristics, while additionally mobilising specific disciplinary theories to provide more granular understandings of the roles of specific actors and dimensions (Geels, 2020). This

development also informs the book's approach and structure, as the next section explains.

1.4 Goals and structure of the book

The book aims to introduce the reader to conceptual frameworks and empirical research from the field of sustainability transitions research, which emerged in the early 2000s and rapidly expanded in the 2010s. This expansion was accompanied by diversification as scholars began to focus on more specialised topics and as unfolding real-world transitions brought new empirical issues to the fore. The book aims to provide a concise yet wide-ranging survey of research strands on these diverse topics and identify unresolved questions and ongoing debates that can stimulate further critical thinking.

Building on other recent overviews (Geels et al., 2019; Köhler et al., 2019), the book is structured as follows. Chapter 2 presents an overarching theoretical framework (the MLP) that offers a 'big picture' understanding of sustainability transitions. This framework is illustrated with two historical examples that show transition processes from start to completion, which is not yet possible for contemporary sustainability transitions as these are still unfolding. Chapter 3 discusses different phases in sustainability transitions and mobilises more specific theoretical insights that deepen the understanding of core processes in different phases. The phases and conceptual insights will be illustrated with selected empirical examples of sustainability innovations from Table 1.1. Chapter 4 discusses the roles of particular actors and dimensions in sustainability transitions, focusing on firms, users, policymakers, and civil society actors. To develop deeper understandings of these actors and dimensions, sustainability transition scholars have mobilised insights from disciplines such as business studies, political science, and cultural studies, as the chapter will show. Chapter 5 discusses insights and findings with regard to several emerging and cross-cutting topics, including acceleration, multi-system interactions, deep transitions, finance, international supply chains, emerging economies, and cities. Chapter 6 ends the book with concluding comments about the field of sustainability transitions research.

Although the development, diffusion, and use of technologies are important in sustainability transitions, this is not an engineering or economics book. Instead, this is a social science book that explains how the actions and interactions of actors over time and in changing contexts can drive or hamper sustainability transitions. The discussion of conceptual frameworks is at an introductory level, although the book does mention deeper theoretical backgrounds for those readers with an interest in underlying assumptions and theories. To empirically ground and elucidate conceptual frameworks, the book uses many illustrative examples that draw from more detailed research in the literature. The examples are mostly about low-carbon transitions in different systems (e.g., electricity, heat, mobility) and in different countries (e.g., United States, Germany, the Netherlands, Austria, United Kingdom). For renewable electricity and EVs, the examples are situated in the context of wider global developments. The wide-ranging topics, examples, and conceptual frameworks will hopefully appeal to many readers and demonstrate the intellectual excitement and dynamism of the sustainability transitions research field.