ANNUAL REVIEWS

Annual Review of Environment and Resources

Sustainability Transitions Research: Transforming Science and Practice for Societal Change

Derk Loorbach, Niki Frantzeskaki, and Flor Avelino

Dutch Research Institute for Transitions, Erasmus University Rotterdam, 3000 DR Rotterdam, The Netherlands; email: loorbach@drift.eur.nl

Annu. Rev. Environ. Resour. 2017. 42:599–626

First published online as a Review in Advance on July 10, 2017

The *Annual Review of Environment and Resources* is online at environ.annualreviews.org

https://doi.org/10.1146/annurev-environ-102014-021340

Copyright © 2017 by Annual Reviews. All rights reserved

ANNUAL REVIEWS **Further**

Click here to view this article's online features:

- Download figures as PPT slides
- Navigate linked references
- Download citations
- Explore related articles
- Search keywords

Keywords

sustainability transitions research, transdisciplinarity, transition governance

Abstract

The article describes the field of sustainability transitions research, which emerged in the past two decades in the context of a growing scientific and public interest in large-scale societal transformation toward sustainability. We describe how different scientific approaches and methodological positions explore diverse types of transitions and provide the basis for multiple theories and models for governance of sustainability transitions. We distinguish three perspectives in studying transitions: socio-technical, socio-institutional, and socio-ecological. Although the field as a whole is very heterogeneous, commonalities can be characterized in notions such as path dependencies, regimes, niches, experiments, and governance. These more generic concepts have been adopted within the analytical perspective of transitions, which has led three different types of approaches to dealing with agency in transitions: analytical, evaluative, and experimental. The field has by now produced a broad theoretical and empirical basis along with a variety of social transformation strategies and instruments, impacting disciplinary scientific fields as well as (policy) practice. In this article, we try to characterize the field by identifying its main perspectives, approaches and shared concepts, and its relevance to real-world sustainability problems and solutions.

Contents

1. INTRODUCTION: SUSTAINABILITY AND TRANSITIONS 600
2. TRANSITIONS RESEARCH: INTELLECTUAL ORIGINS, EMERGENCE, AND OUTREACH 602
3. UNDERSTANDING TRANSITIONS 605
   3.1. Nonlinearity 607
   3.2. Multilevel Dynamics 607
   3.3. Coevolution 608
   3.4. Emergence 608
   3.5. Variation and Selection 608
4. DIFFERENT APPROACHES IN TRANSITIONS RESEARCH 608
   4.1. Socio-Technical Approach 609
   4.2. Socio-Institutional Approach 610
   4.3. Socio-Ecological Approach 611
5. GOVERNANCE IN TRANSITIONS RESEARCH 612
   5.1. Multi-Actor Dynamics 614
   5.2. Reframing the Problem 614
   5.3. Importance of Visioning 614
   5.4. Importance of Experimenting 614
   5.5. Importance of Learning and Evaluating 615
6. APPROACHES TO GOVERNANCE IN TRANSITIONS 615
   6.1. Analyzing Governance in Transitions 615
   6.2. Evaluating Governance in Transitions 616
   6.3. Experimental Exploration of Transition Governance 616
7. SUSTAINABILITY TRANSITIONS RESEARCH AND ITS CHALLENGES .. 617

1. INTRODUCTION: SUSTAINABILITY AND TRANSITIONS

The term transition is broadly used in many scientific disciplines and refers to a nonlinear shift from one dynamic equilibrium to another. It has been regularly used in disciplines such as demography (demographic transition), ecology (ecosystem transitions), psychology (development transitions), and physics (phase transitions of substances). The term sustainability transitions is increasingly used to refer to large-scale societal changes, deemed necessary to solve "grand societal challenges." In this article, we use this term as shorthand for transitions to sustainability—large-scale disruptive changes in societal systems that emerge over a long period of decades. These sustainability transitions are a threat to existing dynamically stable configurations facing persistent sustainability challenges, and they present opportunities for more radical, systemic, and accelerated change.

A current and by now well-known example is the energy transition. Since at least the 1970s it has been argued that societies need to move away from fossil fuels toward renewable energy systems. But it has been only over the past decade or so that real progress is being made with the diffusion of renewable technologies. It coincides with increasing disruptions in markets for oil and gas, sharp declines in the use of coal, and struggling fossil energy companies. The current dynamics are only partly driven by incumbent actors and are heavily influenced by "outsiders" to the fossil energy system such as cooperatives and cities; companies such as Tesla, Siemens, Ikea, and Google; and social movements such as the divestment movement and the LINGO ("Leave It in the

Ground") campaign. The energy transition is thus much more than merely a technological shift; it is a power struggle and a socio-cultural change having a deep effect on incumbent institutions, routines, and beliefs. It has known a very long period of predevelopment and has in many countries now entered a period of turbulent and chaotic changes with uncertain outcomes. It is disrupting relatively stable energy systems that in their turn are the outcome of historical and similarly chaotic and unpredictable energy transitions. As with in the energy domain, many societal sectors have historically experienced such major shifts and are likely to do so again in the future (1, 2).

At the end of the 1990s (3, 4), an inter- and transdisciplinary research field emerged based on the identified need to anticipate and adapt to such transitions to come and related it to the quest for accelerating sustainable development. Research in this field seeks to better understand the dynamics and mechanisms of sustainability transitions and the role of agency herein to develop better analytical tools and governance strategies. This field of sustainability transitions research (hereafter, transitions research) comprises a large variety of approaches and perspectives that in different ways have furthered insight into the persistency of unsustainable societal regimes and possible transition pathways and transition management strategies to escape lock-in. Since its introduction, the concept of sustainability transitions has been the subject of both scholarly and public debate and has developed into a diffuse international field of both applied and fundamental research. It has evolved to become a highly multi-, inter-, and transdisciplinary field in which the core concept of transitions serves as a bridge between different scientific disciplines and grand societal challenges. The field is increasingly global and covers a broad range of sectors, domains, and societal issues, ranging from energy, water, resources, food, and mobility to health care and education, and transitioning regions, cities, and communities toward sustainability.

In this article, we describe how transitions research developed historically and provide a broad overview of the overarching scientific perspectives and their contributions. This overview is by definition limited and biased. It is limited in that we cannot extensively and completely do justice to all the different concepts, ideas, and perspectives in the field or the various ways in which it relates to established disciplines. The article is also biased in that it is largely based on the authors' understanding and perception of the rapidly expanding field—in this case, a bias toward the origins of the field in the Netherlands and in Western European sustainability challenges in a developed, modern society. We do, however, seek to provide a review of the field that is inviting to scholars with a general interest in sustainability challenges from across the globe by developing a more open and reflexive description of the field. Earlier categorizations of the field (5, 6) identify several dominant schools of thought based on four central analytical concepts: the socio-technical multilevel model, the technological innovation systems approach, strategic niche management, and transition management. Although these four approaches certainly represent dominant concepts in transitions research, we understand these as part of a broader research perspective on sustainability transitions and address these as such.

In this article, we also focus explicitly on how transitions research links to complex sustainability challenges. The field itself holds much research and many perspectives that are not explicit in this link or have no prescriptive ambitions, but in this article we consider all of the research that relates to understanding the dynamics and governance of large-scale nonlinear complex systems change related to grand societal challenges. Such understanding, the transitions research perspective argues, is necessary to address the grand societal challenges related to sustainability. This normative starting point has been very influential in the development of research in the field, explicitly seeking to inform governance and policy for sustainability transitions. Given the increasing recognition of the need and possibility of realizing more fundamental transitions as opposed to following gradual processes for reaching sustainable development, interest in transitions research has been steadily growing. From the very start, transitions research interacted with policy and society, and has

enabled and informed governance concepts and strategies for transitions. A central thesis in the field is that grand societal challenges should be understood as systemic, and that dealing with such challenges is only possible through fundamental systemic changes in societal regimes. The core ambition of transitions research is to better understand such transitions, to anticipate and adapt to undesirable transitions (e.g., ecosystem collapse, economic breakdown, high-impact climate change), and to explore possibilities to advance and accelerate desired transitions.

This perspective brings a sense of urgency and societal engagement to the research as well as the necessity to engage deeply in practical contexts where actors deal with transitions. It is increasingly recognized that such possible or actual transitions are not automatically desirable or beneficial to society at large. This has brought a new perspective to the thinking and practice of sustainable development. From a transition perspective, sustainable development policies and programs have focused too much on reducing unsustainability through optimization, thereby (unwillingly) adding to the lock-in of societal systems (7). At the same time, the transition perspective suggests that momentum for systemic change is building. The Sustainable Development Goals and the COP21 Paris Agreement signal that the need for change is no longer questioned, and the overall direction away from a fossil-based economy is clear. It further empowers and accelerates an enormous amount of disruptive innovations, including technological innovations (e.g., renewable energy technologies, 3D printing, circular design, electric mobility, energy-providing buildings), institutional and economic change (e.g., divestment, sharing and social economy, social entrepreneurship, alternative and digital currencies), as well as changing lifestyle practices (e.g., vegetarianism, ecotourism, low-impact lifestyles, sustainable clothing).

The article is structured as follows. Section 2 describes the intellectual origins and evolution of the field going back to its roots in the 1990s, while acknowledging the sources of inspiration from the decades before. By sketching this history, we show how transitions research has developed as an interdiscipline, that the concept of sustainability transitions has and still is functioning as a boundary object bridging scientific disciplines as well as science and (policy) practice. We illustrate this by describing the intellectual growth, as well as how the research gained a foothold in research funding and policy programs. In Section 3 we describe what we consider to be the shared conceptual basis for understanding transitions as well as the main scientific perspectives in the field and what their specific contributions are. Section 4 describes the different ways in which the role of agency and governance are conceptualized in transitions research, and how these are translated into experimental interventions in real-life contexts. In Section 5 we summarize the position and contributions of transitions research and we reflect on the main challenges and prospects.

2. TRANSITIONS RESEARCH: INTELLECTUAL ORIGINS, EMERGENCE, AND OUTREACH

In this section, we describe how the field and community of transitions research emerged at the intersection between science and policy, including its intellectual origins and expansions, as well its public uptake, outreach, and subsequent funding and support. During the 1990s, the concept of transitions emerged at different places in the scientific community as a novel concept to generally address large-scale societal change and sustainability (8–11). The field of transitions research, as it exists today, can be traced back to at least two major (clusters of) intellectual roots in the 1990s. The first was the broad category of innovation research, including science and technology studies, history of technology, evolutionary economics, and innovation policy (12–15). The second was the partly overlapping fields of environmental studies and sustainability sciences, including environmental assessment, integrated assessment, sustainability governance, and environmental policy (11, 16–18). Although this cluster represents a multitude of different disciplines, the streams

feeding into transitions research addressed complex unstructured sustainability problems in the real world based on integrating different disciplines as well as tacit or lay knowledge. The field of transitions research was fueled by the realization that new research approaches are required to investigate the dynamics of complex societal problems and to guide the development of system solutions to address them.

The initial focus of transitions research was on analyzing transitions in socio-technical systems (e.g., mobility, energy, agriculture). Already early on, the link between the more historical, innovation-oriented transitions research and sustainability and governance scholars led to formulating more abstract implications for government policy. From then on, transitions research broadened the focus toward societal systems more generally (e.g., regions, functional domains, cities) and to reflexive governance for sustainable development (3, 19, 20), including prescriptive design recommendations for transition management. Other more recent intellectual expansions of the field include an increasing focus on geographically delineated systems in transition, such as cities (21) and neighborhoods (22); socio-ecological system understandings; socio-economic trends and new economy phenomena (23, 24); issues of power, politics, actors, and discourse (25–27); and the role of civil society, grassroots initiatives, and social innovation (28, 29). These so-called intellectual expansions are not just a matter of additional disciplinary perspectives. They represent a shift in the object and dimensions of sustainability transitions: from a focus on socio-technical systems to a recognition of socio-ecological, socio-economic, and socio-political systems as equally relevant objects of transition.

Within the growing policy discourse on innovation for sustainability, the terms transition and system innovation first appeared and have continued to be applied as policy concepts. Today, we find this transition concept in various international policy contexts. For example, the European Environmental Agency, in its 2015 synthesis report on "the state and outlook" of the environment, explicitly argued that "living well within the limits of the planet requires a transition to a green economy," and that it is necessary to respond to "systemic challenges" and to integrate "policy approaches for a long-term transition" (30). The Climate-KIC partnerships, one of the Knowledge & Innovation Community (KIC) programs of the European Institute of Technology (EIT), has elaborately integrated transition discourse as well as involved transitions researchers in various education and investment programs, and it recently launched the Transition Hub as a European competence and training center for applied transition management. Future Earth is a 10-year international research program of the International Council for Science that aims to build knowledge about the environmental and human aspects of global change and to find solutions for sustainable development. Future Earth included as one of the guiding pillars in its program the "transformations to sustainability" to guide the debate and knowledge coproduction for global environmental research. Sustainability transitions research has been also adopted by the International Social Sciences Council that further elaborated on the importance to investigate and understand transformations to sustainability as a global agenda for social sciences research for the future. Beyond the European context, the Organisation for Economic Co-operation and Development (OECD) published a synthesis report in 2015 on "system innovation," in which it consulted transitions researchers and drew on transition (management) literature to argue—inter alia—that "the dynamics of system innovation provide a new rationale for policy interventions, based not only on addressing single market failures but on solving interconnected problems through a combination of market mechanisms and policy tools" (31, p. 9).

Among civil society and transnational grassroots networks, there is growing attention to transitions. The Transition Towns network, for instance, facilitates thousands of communities across the world working on "transitioning" neighborhoods and communities toward a more resilient and sustainable future (26). This Transition Towns network cooperates with several other

grassroots organizations, for instance, under the European Network for Community-led Initiatives on Climate Change and Sustainability (ECOLISE), which promotes and supports local communities across Europe "in their efforts to build pathways to a sustainable future" (see their mission statement, here: **http://www.ecolise.eu/**). The Smart CSO (Civil Society Organisations) Lab is an international network of more than 1,000 activists, CSO leaders, and researchers "aiming to fundamentally rethink and redesign how activists and change agents in civil society can effectively work towards a systemic change." This systemic change is referred to as "the Great Transition," and the Smart CSO Lab proposes five leverage points as a basis for "a meta-theory of change for the Great Transition from a CSO perspective," which is based on transitions research literature and its Multi-level Perspective (MLP) (32). Related to that, the Great Transition network, which has its headquarters at the Tellus Institute in Boston, Massachusetts, involves a "global, interdisciplinary group of hundreds of scholars and activists who share a common goal of elaborating visions and pathways for a Great Transition" (**http://greattransition.org/**).

When we look further back into the past, we find that one of the first public networks to explicitly embrace the sustainability transition discourse emerged in the Netherlands at the turn of the century, when the Dutch national government officially announced transition policy. In 2001 the concepts of transition and transition management were introduced in the fourth Dutch National Environmental Policy Plan (NMP4). Four transitions were identified as necessary: (*a*) to sustainable energy, (*b*) to sustainable use of biodiversity and natural resources, (*c*) to sustainable agriculture, and (*d*) to sustainable mobility (5). Transition management was presented as "a strategy to deal with environmental degradation by stimulating sustainable development as a specific aim of policy making" (33). The following is necessary, according to VROM (33):

> To solve the big environmental problems we need system innovation which may take various forms. The [system] innovation may take the form of a societal transformation process that may take one generation or more. For the transformation to happen, economic, social-cultural and institutional changes are needed that reinforce each other. [N]ew parties and innovative technologies play an important role. It is not a matter for the government alone but for the whole of society. [M]anagement of transitions requires a form of process management in which uncertainty, complexity and interdependencies are addressed.

In conjunction with the introduction of the NMP4, the Dutch government funded a national research program to develop a knowledge base for sustainability transitions, which helped to develop the basis for transitions research. This 20 million euro research program Knowledge Network for Transitions and System Innovation (KSI) was funded between 2004 and 2010 as one of 38 knowledge programs to stimulate sustainable innovation in the Netherlands. Together with the other programs, it was part of a wider transition network of organizations, institutes, programs, and partnerships in the Netherlands, with its own conferences, meetings, and communication. This transition network included a Competence Centre for Transitions and the Knowledge Centre for Transitions. Many of the programs that were funded, included international researchers that would partly use the funding to enable meetings with other researchers, not only in the Netherlands, but also beyond. The KSI network used part of the funding to organize the first International Sustainability Transition (IST) conference in Amsterdam in 2009.

After the KSI funding stopped in 2010, many researchers that had been involved in the community from various places of the world founded the international Sustainability Transitions Research Network (STRN). Although the STRN itself is informal and formally unfunded, many of the researchers and institutes involved receive extensive public funding to conduct (applied) transitions research. Today, such research funding is available from several international sources,

including the European Union's FP7 and Horizon Program, the Joint Program Initiative of Urban Europe, and national funding schemes in Europe, Australia, Canada, and Japan. In this way, an increasing global and heterogeneous research field of transitions research has emerged and still is developing. The next section describes some of the analytical core concepts and ideas that are central to transitions research.

3. UNDERSTANDING TRANSITIONS

Transitions in their literal sense refer to the process of change from one state to another. In transitions research, the term refers to the process of change from one system state to another via a period of nonlinear disruptive change. Such systemic change, by definition, is the result of an interplay of a variety of changes at different levels and in different domains that somehow interact and reinforce each other to produce a fundamental qualitative change in a societal system. The notion of transitions, present in many scientific disciplines for more than a century (see also 34), in general thus refers to a qualitative change in the state of a complex system. Transitions research applies this perspective to complex societal systems, asking how these could make a structural qualitative shift from (perceived) persistent unsustainability toward a more sustainable state.

The core idea in transitions research is that disruptive systemic change can be located in so-called regimes: the dominant order in a societal (sub)system. The concept of regime is perhaps the most central notion in transition studies: a dominant and stable configuration in a societal system. In the context of the MLP, the notion of a socio-technical regime was introduced by Rip, Schot and Kemp (13, 35) and further popularized by Geels (36) to help explain path dependency and lock-in of existing socio-technical systems around specific technologies such as the steam engine or coal-fired power plants. It was introduced combined with the multiphase model of transitions (3), which identified four phases of predevelopment, take-off, acceleration, and stabilization, through which a transition occurred. The novelty introduced by this transition perspective was that it understands a dominant configuration or regime in the context of its interaction with changing external (landscape) factors, preferences, and pressures as well as in interaction with emerging novelties, innovations, and alternatives. Societal regimes (e.g., dominant technologies, institutions, routines, cultures) emerge out of historical transitions and develop path-dependently through processes of optimization and incremental innovation. As the broader societal context changes and new radical alternatives develop and emerge, regimes inevitably will enter a process of increased stress, internal crises, destabilization, and shock-wise systemic reconfiguration (37, 38). **Figure 1** shows this original multilevel, multiphase perspective on transitions.

This original multilevel and multiphase concept of transitions emphasized transitions as processes of innovation. Over time these have been extended to include more detailed understandings of the underlying patterns and mechanisms as well as to understand transitions as combined processes of building up and breaking down. Inevitably this is part of how complex societal systems evolve. Path dependency is inevitable because of sunk investments, benefits of scale, and the co-evolutionary dynamic within a regime. But such path dependencies over time ultimately imply the inability to change beyond optimization, hence causing systemic tensions and problems. Once disturbed by external crises, internal tensions or better alternatives (37, 39, 40), reorganization toward a new equilibrium is by definition shock-wise and whimsical, creating chaotic and unpredictable patterns of change. Where initially experimentation and acceleration were the main foci in transitions research, in recent years increasing attention is given to processes of destabilization, emergence, and institutional change. By building on historical cases as well as reflecting on and analyzing currently evolving transitions, a theoretical basis has been developed that identifies the different patterns and mechanisms of change that drive nonlinear structural change in complex

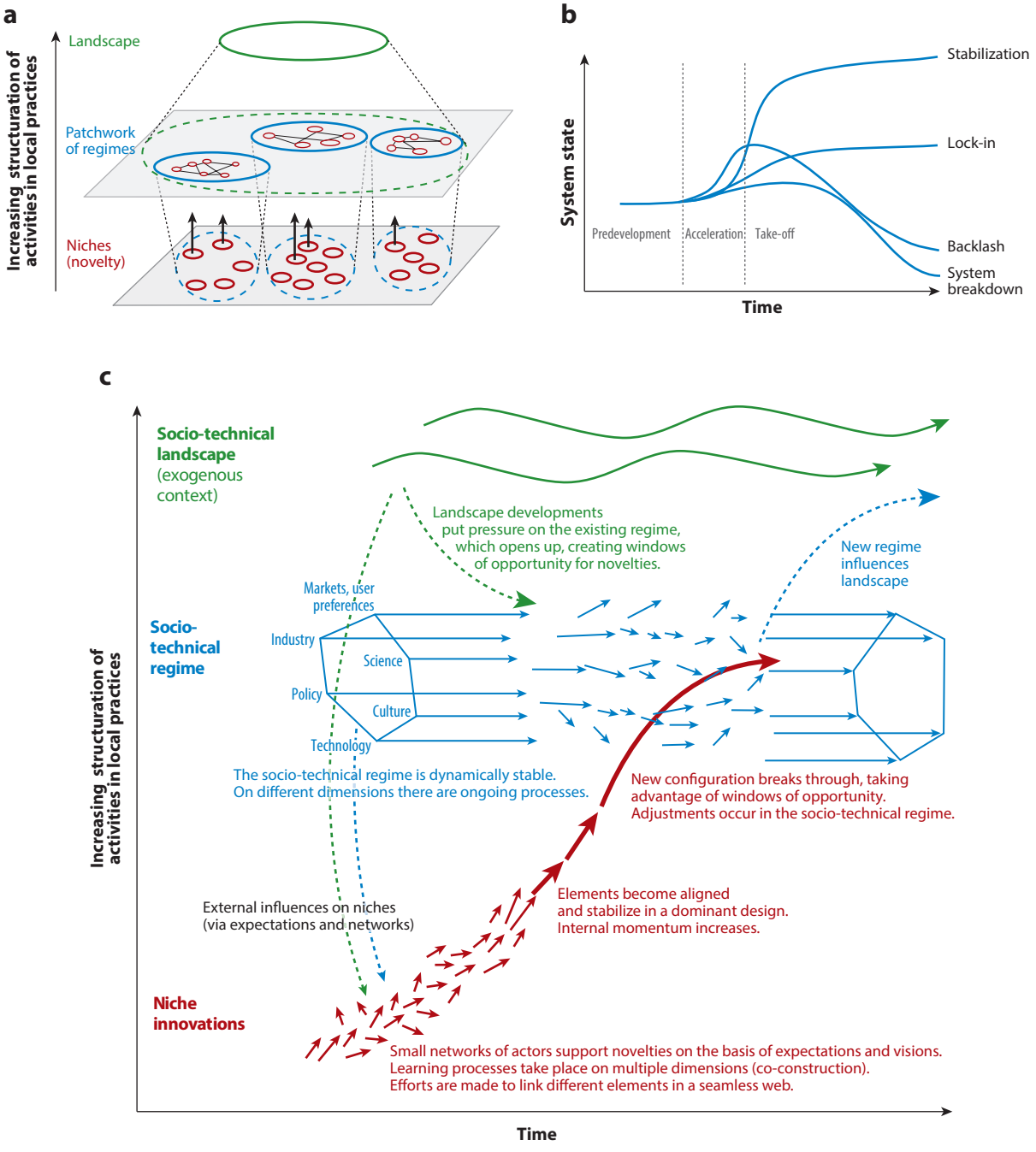


Figure 1

The original multilevel, multiphase perspective on transitions with (*a*) the multilevel model depicting the coevolution between landscape, socio-technical regimes, and niches; (*b*) socio-technical regime change as result of coevolving landscape pressures and emerging niches over time; and (*c*) the multiphase concept illustrating the nonlinearity of transitions and different types of pathways. Panels adapted with permission from References 35, 4, and 124, respectively.

societal systems. **Figure 2** shows this analytical model to understand and study the dynamics of transitions.

This analytical model of transitions provides a systematic way to reflect on ongoing and past transitions as evolutionary revolutions in complex societal systems. It builds on several core concepts that bring more specificity to understanding the type of change inherent to transitions and to understanding how transitions research studies complex changes in society. These are the following.

3.1. Nonlinearity

Transitions are disruptive changes that develop in a shock-wise manner rather than in a gradual way. Research in the field therefore distinguishes change in general from transitions insofar as it is concerned with stepwise changes into a qualitatively different state. The notion of disruptive change is present in many disciplines that are drawn upon by transitions researchers. Perhaps most prominent is the idea of punctuated equilibria and tipping points in evolutionary biology and ecology. But similar nonlinearities are studied in innovation sciences, often referred to as disruptive innovation.

3.2. Multilevel Dynamics

Transitions are located in a particular system but are always conceptualized as the result of interacting dynamics at multiple levels. The most basic distinction that is shared within the field is that between the context (landscape), the dominant configuration (regime), and alternatives (niches) (41). But the concept of transitions implies a nested perspective: The transitions on which we focus are also part of higher-level transitions, and include lower-level transitions. Analytically, this means that transitions are always related to their context and that attention is given to interscale

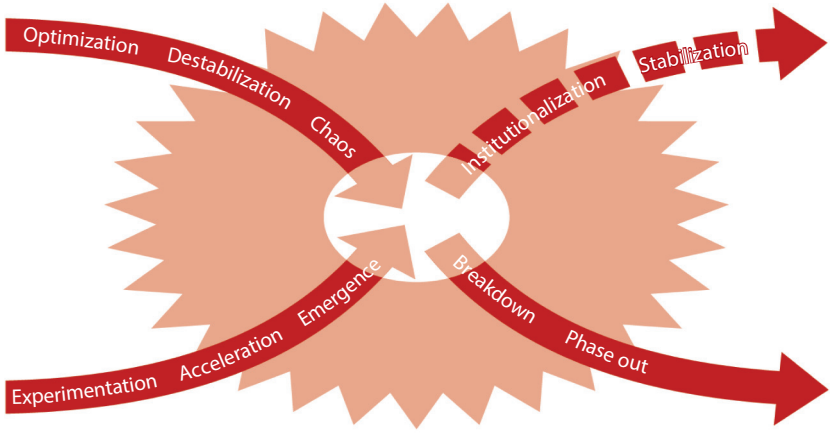


Figure 2

Dynamics of societal transitions as iterative processes of build-up and breakdown over a period of decades. In a changing societal context, established regimes develop path-dependently through optimization, while change agents start to experiment with alternative ideas, technologies, and practices. Over time pressures on regimes to transform increase, leading to destabilization as alternatives start to accelerate and emerge. The actual transition is then chaotic and disruptive and new combinations of emerging alternatives and transformative regime elements grow into a new regime. In this process elements of an old regime that do not transform are broken down and phase out.

dynamics, be it technologically (e.g., upscaling), institutionally (e.g., multilevel governance), or spatially (e.g., spatial diffusion).

3.3. Coevolution

The nonlinear and multilevel understanding of transitions also includes an understanding of complex system change as the result of interacting types of changes. What is studied is not innovation or change in one dimension or domain, but by definition, across domains. It is based on the notion that innovation itself is a systemic process whereby, for example, technological innovation interacts with social and institutional changes in a coevolutionary way, meaning that through their interaction the interacting elements themselves also change (42, 43). In transitions research this is often referred to as multidomain, and in practice implies including a variety of technological, social, economic, ecological, and institutional factors in the analysis. Coevolution implies thinking beyond linear causalities: It is not a matter of asking what comes first or what causes what, but rather a matter of acknowledging how different phenomena shape and relate to each other over longer periods of time.

3.4. Emergence

Closely related to the coevolutionary perspective is the notion of emergence and surprise. The concept of transitions implies the emergence of a new dynamically stable order out of a process of chaotic, coevolutionary change. In other words, transitions are the outcome of all sorts of actions and changes that somehow lead to new structures in a way that was not foreseen or planned in advance. Besides the practical impossibility of predicting the outcomes of complex societal changes over a period of decades, the notion of emergence in transition studies thus also refers to the insights from complex systems theory relating to chaos and order. Transitions are considered to be societal processes of fundamental change including emergent and coordinated characteristics. Coordinated emergence describes the principle of radical change in incremental steps. In this way, a transition can be coordinated by creating shared future orientations and guiding values and at the same time creating space for experimentation and diversity in the short term, allowing for new solutions and ways of organizing to emerge.

3.5. Variation and Selection

Novelty as outcome of a processes of experimentation and learning-by-doing (either technological, institutional or governance innovation) plays a crucial role in the way sustainability transitions are instigated, accelerated, and triggered. Different approaches emphasize various forms of innovation and how they relate with the disruptive novelty creation and ultimately systemic change. More recent work in sustainability transitions research also focuses on the role of social innovation produced by civil society (initiatives, organizations, social business models, movements) in sustainability transitions. This focus on transformative social innovations also broadens the understanding of innovation and the ability to develop effective innovation policies or strategies to include altering values and beliefs at the collective level, creating and establishing social-ecological lifestyles, and reflexive practices as experiments contributing to transitions.

4. DIFFERENT APPROACHES IN TRANSITIONS RESEARCH

The core ideas in transitions research have been taken up in a range of disciplines, domains, and research fields. Depending on the entry point, transitions researchers approach the question

of large-scale societal change in different ways: as technological, institutional, social, ecological, economic, or cultural. This has led to the development of theories and perspectives on different types and dimensions of transitions or, arguably, different angles or perspectives on sustainability transitions based on the main societal problem or solution taken as a starting point. We argue that the strength of the field is that it allows for very fundamental differences in ideas about the role of research and how to approach research on transitions, while at the same time enabling debates across disciplines and approaches through the joint language and concepts of transitions. This has led to ongoing debates between different perspectives with regard to the nature of "what" is involved in transition, how that can best be studied, and what the insights imply for practice. These debates create the kind of dynamic, exchange, critical reflection, and intellectual deepening that has driven knowledge development and integration.

The most central debate concerns the notion of transition itself, represented in the three parts of Grin et al.'s (4) *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*. Part 1 represents the historical perspective on transitions, which reconstructs historical socio-technical system changes and argues that transitions can be analyzed only in hindsight. Part 2 represents the focus on recent (contemporary) and emerging transitions, assuming that the underlying patterns and dynamics of historical transitions can be used as bases for hypothesizing possible future patterns and possible interventions. This part of transitions research rather anticipates and explores the possibility and desirability of future transitions as an inevitable outcome of path dependencies that produce symptoms of unsustainability. Part 3 represents the more external reflexive approach that understands transitions as emerging and whose research functions to describe and reflect on unfolding patterns of change. Each approach has its merits and specific understandings of the role of researchers, and transitions research does not strive for consensus or uniform definitions. Transitions research aims to offer frameworks, concepts, and a language that helps to facilitate and structure discussion and reflection across different disciplines and domains.

Many of the ongoing debates within transitions research relate to the differences in epistemological and disciplinary backgrounds from which transitions are studied. In the next sections, we describe three dominant and prominent approaches and the motivations behind these. We use the term approach to refer to the way the topic of transition is approached scientifically, epistemologically, and normatively. Although some are more driven toward description and conceptual understanding, most of the transitions research explicitly pursues a normative goal, i.e., understanding sustainability transitions. The three approaches we discern are similar in their interest and focus on transitions but different in how they seek to understand these, what the core subject of transition is, and which drivers and mechanisms they attach the most explanatory value to. We discern the following distinctive research approaches to study transitions, each with their own respective disciplinary and methodological backgrounds and objectives: socio-technical, socio-institutional, and socio-ecological.

4.1. Socio-Technical Approach

The socio-technical approach has its roots in science and technology studies and lies at the roots of transitions research. Although there is increasing attention to other approaches, many transitions researchers take a socio-technical approach to studying transitions. Socio-technical regimes that have emerged around dominant technologies are the subject of transitions. Innovation takes a prominent role in understanding the dynamics of path dependency, sunk costs, lock-in, and disruption. Typical examples under study are systems in which infrastructures and technologies play an important role: energy, mobility, or water. Two major analytical lenses include the MLP and the Technological Innovations Systems (TIS) framework.

Studies into socio-technical transitions are heavily influenced by the MLP and research into the history of technology (13). In general, empirical studies are considering processes of technological substitution (e.g., from horses-and-carriage to automobile) as a result of the interplay between incumbent regime structures, external landscape pressures, and emerging niches. Such niches are considered as protected spaces necessary for innovations to mature vis-à-vis incumbent socio-technical regimes. Niche creation and development can be a market based or a government-driven process. On the basis of several empirical case studies, different transition pathways have been conceptualized (40), as have the evolution of niches and how they can be understood (44, 45).

Within socio-technical transitions research, innovation journeys (46) are reconstructed through desk research and data analysis to map the patterns and dynamics of regime change. The origins of this perspective are innovation studies, history of technology, constructive technology assessment, and economics of innovation (47). The MLP is increasingly used to assess the potential of emerging and desired technologies against the background of incumbent structures and technologies. The insights stemming from socio-technical research provide basic starting points for nurturing and managing niches (see Section 5).

A related perspective that has a more explicit focus on innovation policy is that of TIS (48), which understands (technological) innovation as a systemic process in which technologies coevolve with an emerging market structure, a governance context, and user preferences (49, 50). Without explicitly considering an incumbent regime context, TIS seeks to understand the mechanisms that enable technological innovations and provides an assessment framework according to governance guidelines. These are conceptualized as the "motors" of innovation (51), e.g., those factors that determine the extent to which a new technology is able to scale up and diffuse into an existing market.

4.2. Socio-Institutional Approach

This term refers to a wider range of approaches that draw from social sciences to understand systemic changes in complex societal systems. These approaches draw from social sciences such as economics, political science, sociology, governance studies, and geography. We refer to these as socio-institutional, as these approaches identify institutionalized cultures, structures, and practices (52) as regimes in which transitional change takes place. These approaches often focus on specific sectors or geographical areas that face persistent problems. Although technologies might play an important role in understanding transitional change, the emphasis is rather on how incumbent routines, powers, interests, discourses, and regulations create path dependencies and how these are challenged by (transformative) social innovations. The socio-institutional perspective is applied to societal systems facing persistent environmental challenges such as mobility, waste management, and energy but increasingly also to systems such as health care, education, finance, and democracy. Examples of this approach are studies on societal transitions (23, 53), practice-based transitions (54), transitions in consumption and production (55, 56, 57), and spatial transitions (58). Typically this approach focuses explicitly on the role of agency and governance in such transitions and takes a more reflexive stance. It highlights issues of normativity, ambiguity and social construction (59) as well as reflects upon the interaction between multiple regimes (60). In addition, there is attention for social learning (61), culture and daily practices as factors that have a strong influence on the direction and dynamics of transitions.

In the socio-institutional approach, institutional dynamics (62, 63) are addressed more prominently to explain inertia and lock-in as well as to critically explore issues of power, politics, and agency (64–66). These have led to a series of theoretical and empirical studies into power and politics in transitions (25, 67–70). These include research on dialectics and Trojan horses (71),

international energy policy, development in relation to transitions, and politics of space (72, 73). These studies emphasize that sustainability transitions are inherently political as they imply systemic change often directly. But they also draw attention to socio-political transitions themselves, such as the transition in democracy (74) and from centralized governance structures to decentralized, not-for-profit community-based and/or Third-Sector-based energy cooperatives (75, 76). More attention for such socio-political dimensions is being developed concurrently with adjacent fields of grassroots innovation and social innovation (77, 78). Increasingly, attention is drawn to applying transitions research to governance systems and democratic regimes as such, considering the current ways in which societies are organized as dominant locked-in regimes that are vulnerable to transition pressures (73). The focus on socio-institutional dimensions of change often relates to a more normative orientation toward emerging or ongoing transitions and therefore also draws on different types of methods and epistemologies than the socio-technical approaches that tend to be more analytical and descriptive. In this approach, also more qualitative, action-oriented, and transdisciplinary methods are common.

4.3. Socio-Ecological Approach

A third distinct suite of approaches builds on insight from ecology, biology, complex adaptive systems theory, ecosystem services, and adaptive governance. The socio-ecological approach has its roots in ecology and resilience theory (79), seeking to understand (in)stability in ecosystems but evolved to look at coupled socio-ecological systems. Transitions in ecosystems are understood as nonlinear shifts from one attractor basin to another passing certain "tipping points." These shifts from one dynamic equilibrium to another are nonlinear, almost irreversible, and follow a pattern of buildup, stabilization, breakdown, and recovery (80). Within the resilience approach, the interplay between such ecological transitions and the societal context is addressed, and it examines the way in which this context pushes ecosystems beyond tipping points and planetary boundaries (81, 82). Research on planetary boundaries provides a frame of reference for mapping and assessing the accelerated impacts of anthropogenic activities and connects with the ways the UN Sustainable Development Goals can facilitate a process of tackling global change by addressing the interconnected planetary boundaries. Planetary boundaries provide also the frame of reference for actions required to re-establish planetary resilience and are signposts on thresholds of socio-ecological systems and their change. Here often the term transformation is used to address the need for systemic sustainable solutions, whereas resilience is related to the ability of a system to withstand shocks while maintaining function as well as to transform anticipating external pressures, shocks and threats. Interestingly, the resilience perspective has originated from the desire to sustain ecosystems in their current "attractor basins" (similar to the notion of regime) and to prevent catastrophic collapse. The concept of resilience found applications in broader domains including policy and planning with often a non-normative understanding neglecting that there is desirable and undesirable resilience in systems; for example, corruption is an undesirable but very resilient system. Resilience research in general has a very long history and applications in understanding its drivers and institutions, but more coordinated research into socio-ecological transitions did not develop until the 1990s.

The socio-ecological perspective is applied in different ways, including a focus on metabolism (83), external catalyzing events (84, 85), or the alternation of different dynamic processes (also known as panarchy) (80). Over the past years, the socio-ecological perspective has increasingly engaged with issues such as biodiversity and nature, nature-based solutions and ecosystem services, and climate resilience (86). Inevitably also more attention to the role of agency and governance has developed producing concepts such as adaptive governance and stewardship (87, 88, 89).

Table 1 Three different perspectives on sustainability transitions

	Socio-technical	Socio-institutional	Socio-ecological
Disciplines	Innovation studies, history, technology, science and technology studies, practice theory	Sociology, governance, policy, economics, geography, political science	Ecology, biology, governance
Focus	Technology in social context Analysis of (historical) innovation journeys	Institutions, agency, power Analysis of networks, social innovation and governance	Ecology and socio-ecological relations Analysis of system vulnerability and transformative capacity
Main analytical lenses	Seamless web, multilevel perspective, path dependency, strategic niche management	Culture, structure, and practices; power in transition; transition management, multi-actor perspective	Panarchy, resilience, adaptive and transformative capacity, navigating, planetary boundaries
Approach to the energy transition	Emphasis on technological innovation, e.g., transition from combustion engine to electric car or from coal-fired power plants to solar panels in a societal context through dedicated innovation policy	Emphasis on political and institutional change, e.g., from central to decentral energy production as a shift in power from centralized monopolies to decentralized networks through countermovement and disruption	Emphasis on ecological thresholds and extraction of fossil resources to renewable resources within closed cycles through adaptive management

By studying dynamics in a great variety of socio-ecological systems, research has been able to identify different types of human-ecosystem interactions that either negatively influence ecosystem resilience or might help to strengthen it. These are captured by theoretical concepts and insights relating to thresholds, maladaptive persistent states in complex systems, and panarchy. But often it is argued that transitions in social contexts are necessary to sustain the stability of ecosystems and/or enhance their capacity to deal with disturbances (through transformation) (90). **Table 1** summarizes the different perspectives and their specific characteristics; **Figure 3** illustrates the three approaches and typical empirical domains of research.

5. GOVERNANCE IN TRANSITIONS RESEARCH

Analytically, the understanding of transition processes can be distinguished from the understanding of how actors (can) influence transition processes: The first object of study is referred to as transition dynamics, the latter as transition governance. The question of governance in sustainability transitions is at the heart of transitions research. The main driver behind the emergence of transitions research has been the search for new insights and ideas to understand how to steer clear from unsustainability lock-in and how to mobilize and empower disruptive innovations and transformative capacity from the system toward desirable sustainability transitions. To this end, the system (dynamics) approaches provide a useful analytical basis but also a starting point for exploring the role of agency in transitions and specifically on how agency might influence the pace and direction of transitions and ultimately how such agency can be stimulated to contribute to sustainability transitions. This thinking positions transitions research as a field that asks new questions for governance—not only understanding the ways that existing instruments and institutional responses contribute to sustainable ends but also the inner workings of policy and governance. Transitions research advocates that governance is a multi-actor process in which systemic solutions, disruptive innovations, and (reflexive) institutions are formed by experimenting and learning.

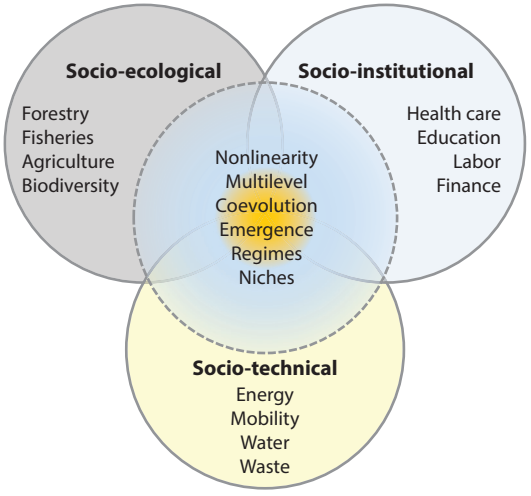


Figure 3

Three approaches to studying sustainability transitions that each present different ways to understand sustainability transitions, in a more socio-technical, socio-ecological, or socio-institutional way. Although these approaches share a similar interest in the nonlinear process of transitions, they come from different disciplinary and epistemological backgrounds and bring different types of insights and methods to sustainability transitions research.

Transition governance ideas build on the idea that the network society facilitates all sorts of ways through which actors organize themselves to produce solutions to societal problems drawing on insights from governance literature around (meta-)governance (91–93) and network governance (94–97). Transition governance then seeks to influence how actors do this and how different types of agency add up by adding the perspective of transitions as regime shifts in societal systems that are by definition (partly) initiated outside incumbent structures, vested interests, and dominant institutions during predevelopment and destabilization. Combined with the argument that dominant governance logics of state and market are at odds with sustainability, transition governance generally calls for targeted strategies to empower context-specific transformative solutions developed in multi-actor networks. This implies, for example, a specific focus on radical and transformative technological and social innovation in earlier stages of transitions as well as strategies focused on dealing with regime destabilization and institutionalization of emerging transitions.

The field of sustainability transitions by now includes several different approaches to understanding and operationalizing transition governance, including strategic niche management (40), reflexive governance (98), transition management (99), and policies for innovation systems (50). What these different approaches have in common is particular attention for system innovation and socio-technical coevolution. This diverse subfield of transition governance can in turn be positioned in relation to the broader context of an environmental governance for transformation (82, 100, 101) and sustainability governance (102, 103). The diversity of analytical perspectives to understand transitions is thus complemented with a perhaps even larger diversity of approaches toward their governance. As Patterson et al. (104) summarize, "a variety of conceptual approaches have been developed to understand and analyze societal transition or transformation processes, including: socio-technical transitions, social-ecological systems, sustainability pathways, and transformative adaptation." These approaches, albeit different, also share many common characteristics and elements summarized below.

5.1. Multi-Actor Dynamics

Several transition scholars have emphasized how transitions involve multiple actors from various institutional backgrounds (e.g., market, government, science, civil society) and that the shifting power relations and role constellations between different actors is inherent to any transition process (25, 26, 105). Acknowledging that some actors might be more related to regime contexts than others and that individuals might be more flexible in relating themselves to niches or regimes draws attention to issues of power asymmetries and the different types of influence actors have (63, 106, 107). Transitions research therefore seeks to understand how different types and forms of agency influence the speed and direction of transitions and how they can be engaged, can be empowered, and can more effectively contribute to desired transitions. This includes an interest in processes of institutional change and structuration as well as in roles of radical outsiders, frontrunners, or marginalized groups.

5.2. Reframing the Problem

Societal consensus around problems influences where investments and actions are directed. Historical transitions underline the importance of such discursive changes at the societal level through which persistent problems are recognized and translated into new future directions and ultimately into interventions. An important element in transition governance is therefore the support and development of shared and deeper insight and the need for systemic change. It uses transition concepts to broaden the ways in which actors understand complex societal problems. It does so by introducing thinking in terms of symptoms of underlying persistent problems, path dependencies and lock-in, and unproductive niche-regime interaction. Going through such processes in a participatory way stimulates development of a (new) shared discourse (108–110).

5.3. Importance of Visioning

An important driver for innovation and experimentation at all levels is the belief actors have in alternative futures and fundamental values that they strive to realize. Visioning alternative system futures, scenario-building, and backcasting (111, 112) are therefore important tools in transition governance to facilitate and empower actors and networks, so that they can more strategically work on transitions, explore more radical innovation trajectories, and formulate alternative goals and agendas. A vision is useful in giving direction, but the importance of the vision itself should not be overstated as there are often many different visions competing in a context where all sorts of uncertainties and seemingly random events might take over. The role of visions in transition governance is thus mainly to motivate, coordinate, and empower actions in the short term and medium term (113).

5.4. Importance of Experimenting

As transitions are complex and unstructured processes of change, a process of learning-by-doing and doing-by-learning is the only way to adapt, change, and transform existing dominant cultures, structures, and practices. The transition perspective views alternatives to the dominant as experimental as they might inform how a desired transition might unfold. Experimenting is therefore a way to unpack complexity and to gather evidence on the new relations and new roles that a transition requires. Sustainability transitions therefore require technological, organizational, place-explicit, and governance experimentations (114–116).

5.5. Importance of Learning and Evaluating

In real-life contexts, achieving social innovation, by definition, implies social learning: reshaping social interactions, roles, knowledge, language and practices. It is evident that besides transfer of knowledge, contexts also influence behavioral and mental change in actors. Thus, transition approaches seek to develop (physical, emotional, network, process) contexts that make actors reflect, rethink, and reshape their thoughts and actions (117, 118). Transition governance therefore calls for continuous learning and adapting. Systematic transition monitoring and evaluation can help reflect on how deliberate actions interact with broader societal transition dynamics and vice versa. Such systematic reflections that focus on dynamics and processes rather than implementation or output can help to reorient interventions and identify new opportunities (119, 120).

6. APPROACHES TO GOVERNANCE IN TRANSITIONS

There are three distinct ways that transitions research is seeking to address the questions of agency in (sustainability) transitions and formulate ideas and approaches for intervening in transitions in order to guide and accelerate these to sustainability. These are theorizing and analyzing governance in transitions, evaluating formal (transition or innovation based) policy in transitions, and experimental exploration of interventions in transitions (see also **Figure 4**). We provide an overview of all three approaches.

6.1. Analyzing Governance in Transitions

As government organizations and established policies are by definition part of dominant regimes, transitions research seeks to understand the role of societal forms of agency at different levels

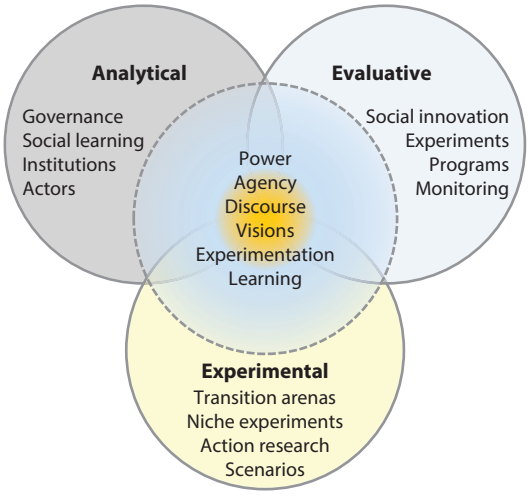


Figure 4

Three approaches to governance in transitions research that represent different ways to study and conceptualize the role of agency and intervention. They all relate to sustainability transitions by focusing on issues such as the role of power, discourse, and experimentation in influencing sustainability transitions. But these approaches differ in terms of their scientific approaches and because they produce different tools and instruments for analyzing, evaluating, or experimentally influencing (transformative) agency in the context of sustainability transitions.

and how they might interact with institutional and policy change. The perspective of reflexive governance (121, 122) more broadly looks at how interaction patterns between different actors in the context of persistent problems and transitional dynamics (do not) lead to learning, behavioral change, and ultimately systemic change. This broader perspective is applied to different types of transitions such as the transition in water management (123, 124). The more specific framework of transition management has also been applied as a descriptive lens to understand and explain the impact of governance processes on past transitions through retrospective case studies (73). Examples are reconstructions of how individuals and transition arenas influenced or "managed" the course and direction of historical transitions such as in urban water management (63, 116, 125) and waste management (126). Such studies show how an alternative "transition" discourse emerged in coevolution with transformative networks, increasing regime tensions, and growing societal pressure. Such networks were able to "play into" incidents such as floods or droughts to advance sustainability transitions toward adaptive water governance.

The approach of strategic niche management builds on the idea of niches as incubation spaces for disruptive innovations that are in practice often facilitated through government interventions. SNM has informed and served as a framework to analyze niche emergence in specific sectors such as energy (127, 128) and to examine movements active in urban contexts (129, 130). SNM and constructive technology assessment (131) are used to explore the role of social and technology learning in socio-technical transitions (132). Recognizing key requirements of such learning processes, tensions between government levels regarding the role of local needs for directing innovations are addressed.

6.2. Evaluating Governance in Transitions

Since the beginning of the take-up of transitions research in formal policy programs, starting with the Dutch energy transition program, policy scholars have been using the transition perspective to reflect on and evaluate transition policies. This research deepens our understanding of the role of policy in sustaining existing regimes and advancing sustainability transitions. Some studies critically reflect on the implementation and use of transition management in public policy, debating issues of political and power asymmetries (133–136), dilemmas of participation, unmanageability of transitions, and the incumbent role of central government itself (137–141). But more broadly does this type of research investigate to what extent explicitly transition-oriented policies work and in which types of policy mixes (142, 143).

But transition perspectives also serve to evaluate more general, innovation-based policies and formulate recommendations to gear innovation policies more toward transitions. The TIS approach, for example, was and is used in various ways to structure policies for innovation pathways, evaluating the developed transition agendas, and formulating new policy interventions (50, 51, 144). Such evaluative studies have also been applied in health care (52), agriculture (145, 146), and mobility (147). These studies inform policy processes by providing a broader transition perspective and raising questions about the focus of innovation, for example, questioning the integral nature of policies that often lack attention to upscaling or institutionalization, or raising attention to incumbent and competing policies in other domains. Such evaluations often create the space for experimental governance processes.

6.3. Experimental Exploration of Transition Governance

There are several operational tools based on transitions research to try to influence the speed and direction of transitions. Examples of such tools are transition arenas, scenarios, and experiments

(see also **http://www.transitiepraktijk.nl/en**). We describe two approaches that have from the beginning sought to provide an integrated framework or approach to influence specific dynamics in transitions. These take the insights into the system and agency dynamics in transitions as a starting point. These are strategic niche management (41, 115, 148, 149) and transition management (3, 19, 99, 150). Strategic niche management can be regarded as both a research model as well as a policy tool (115) and refers to the process of deliberately managing niche formation processes through real-life experiments. The core idea is that through experiments with new technologies and new socio-technical arrangements, processes of coevolution can be stimulated (35, 43, 151). Technologies as well as the contexts (e.g., user preferences, networks, regulation, complementary technologies, expectations) in which they develop are worked on simultaneously. Consequently, new, more sustainable patterns might emerge, partly embodied in new technologies and in new practices based on new experiences and ideas (151). Such experiments can be envisaged as (part of) a niche in which technologies are specified and consumers are defined and concretized. Experiments make it possible to establish an open-ended search and learning process, and to work toward societal embedding and adoption of a new technology (148).

Transition management provides a framework and set of tools developing transition-based governance strategies, including a broader range of governance instruments such as transition arenas, transition scenarios, transition experiments, and transition monitoring. Over the past 15 years, transition management has been applied to a diverse range of sustainability questions, policy contexts, and geographical scales (73, 152) and has become one of the most prevalent approaches currently used in parts of Europe to scientifically ground and advance in practice the governance of sustainability transitions. The applications have shown that the approach is able to support governance of, and for, sustainability transitions (72, 73, 153, 154). In practice especially, the transition arena has served to create new networks, discourses, transition agendas, and experiments, influencing policy and practice. Reviewing transition management applications in developed (Western) European contexts, Loorbach et al. (59) acknowledge that transition management is "so far not achieving the aspired large scale systemic changes." They identify several challenges in relation to governance interventions including the question of inclusivity (of, e.g., marginalized perspectives), facilitation techniques for social learning and capacity building, and regime persistence. This points to current research directions for transition management, such as explorations of institutional change and formal policy (27, 52, 62, 63, 74), new forms of power (25, 75, 155, 156), and the role of researchers (157).

7. SUSTAINABILITY TRANSITIONS RESEARCH AND ITS CHALLENGES

The field of sustainability transitions has evolved rapidly over the past 15 years. It has become a distinct area of research into the nonlinear dynamics of societal change, highly relevant to policy and society in the context of grand societal challenges. It has produced several innovative concepts, approaches, and instruments that support interdisciplinary and applied research and serve innovation practices and policy. It has shaped understanding in policy and society when it comes to complex persistent problems. Transition concepts have been used as an underlying rationale for certain policy programs at local, national, and international levels and are used as an approach to facilitate transformative networks and experiments and to evaluate innovation policies. It has added to the development of inter- and transdisciplinarity in academia and is at the forefront of what is now increasingly referred to as transformative science (158, 159). This is reflected in the way that the field has coevolved with societal change and public discourse, iterates

with society, and continuously adapts to new issues and questions. This way the field achieves plurality while maintaining coherence and direction.

We have shown that although the field is multidisciplinary, indeed it should be characterized as a true field given the shared—even if diverse—notions among the several disciplines, a shared interest in a specific type of societal change, and the development of a set of structures to facilitate exchange and cooperation. Besides the structural characteristics of a field (e.g., network, journal, conferences), it also has a specific culture of interdisciplinarity and quite active groups doing research at the intersection between science and society. In this article, we have tried to describe the emergence and diversity of transitions research. Transitions research ranges from formal (theorizing and describing dynamics in complex societal systems) to interdisciplinary (analyzing specific complex societal problems) and applied (experimental testing of hypotheses). We have also touched on the diversity of contexts in which the different transition approaches are applied, ranging from environmental to economic and spatial systems.

The growing diversity and increasing societal relevance also pose serious challenges for transitions research. Transitions research developed from a marginal, radical idea advocated by a limited number of researchers (niche level) to having shared structures, a dominant discourse, and shared practices (niche regime). Such regime characteristics might also complicate further broadening and scaling up of the field as it possibly comes with, for example, superficial uses of the concepts, fueling skepticism and resistance against the transdisciplinary nature of the research or its "objective" to address such complex and large-scale change. But this lock-in might be enhanced by scholars in the field itself, once the frontrunners and now regime actors that might become defensive and unwelcoming to radically renew, revise, or reinvent dominant models and frameworks in an ever changing societal context.

A challenge for the field is thus to stay open to new ideas and different types of societal challenges and contexts while maintaining the critical reflexivity and core concepts to facilitate the interdisciplinary exchange. New issues that are already emerging, within the context of the current transition management regime, are, for example, investigating processes of destabilization and collapse (39), economic stagnation and degrowth (160), transition in the democratic system (74), and bridging the gap between descriptive analytical transition dynamics and prescriptive transition policies (39, 52). However, to really bring the academic and societal potential of transitions research to a new level, there is a need for an opening up toward even more heterogeneous perspectives and approaches and a critical reflexive evaluation of the field itself. One of the main challenges will be translating transitions research to developing contexts. So far developing countries and their sustainability challenges have been only sporadically addressed in transitions research even though the urgency and gravity of the problems are enormous. Another big challenge is dealing with actual crises and shocks emerging in many transition domains: How resilient is the transition theory itself as ideas on experimentation and analysis seem to be rather insignificant in the context of large-scale disruptive change? Only if transitions research can keep opening up to new perspectives and challenges can it renew its capacity for innovation, strengthen its transformative academic impact, and enlarge its contribution to societal sustainability.

By its diversity and societal orientation, we characterize sustainability transitions research as a transdisciplinary field, acknowledging that it also involves disciplinary, positivist, and theoretical approaches (158, 161, 162). Combined, do all these different approaches and perspectives in a way reflect the inherent complexities of the challenges of sustainable development? In that way, the field of sustainability transitions research fits within a broader debate around the changing role of science under the headers of "postnormal" (163) or "sustainability science" (158, 164). When considering the academic merits of transitions research and its contribution to sustainability science, points for consideration include the explicit focus on processes that activate sustainability and the practices of

sustainability research at universities (165, 166). Transitions research therefore has a very specific identity, as it has developed around a recognizable and shared focus on a specific type of change and has a very strong social science/applied side, whereas (especially the US interpretation of) sustainability science aligns closer with natural sciences.

Thus, the very idea of researching sustainability transitions as an act of governance in such transitions gives transitions research a very specific character. It necessitates continuous critical self-reflection, multi- and interdisciplinary debates, and strong feedback loops from practice, either through societal engagement or exchange (161, 167). To cover the whole spectrum required to produce theory and hypotheses, experimentally test these in real life, critically reflect, and revise, there are many different epistemological positions in the field. These range from modeling (37, 168, 169) and conceptual (62, 170) to empirical and applied research (171). It is impossible to be complete, but the richness of positions and perspectives arguably is a big strength of transitions research given that in this way, it facilitates the common research journey supporting the societal search for sustainability (167, 172).

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

This article was made possible by the support of the ARTS project (**http://www.acceleratingtransitions.eu**), which is funded by the European Union's (EU's) Seventh Framework Program (FP7) grant agreement 603654, and the Transformative Social Innovation Theory (TRANSIT) project, which is funded by FP7 grant agreement 613169. The views expressed in this article are solely the responsibility of the authors and do not necessarily reflect the views of the EU. The authors are very grateful for Sarah Rach in assisting with finalizing an earlier version of the article.

LITERATURE CITED

1. Sovacool BK. 2016. How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Res. Soc. Sci.* 13:202–15
2. Verbong G, Loorbach D, eds. 2012. *Governing the Energy Transition: Reality, Illusion or Necessity?* New York: Routledge
3. Rotmans J, Kemp R, van Asselt M. 2001. More evolution than revolution: transition management in public policy. *Foresight* 3:15–31
4. Grin J, Rotmans J, Schot J, (collaboration with) Geels FW, Loorbach D, eds. 2010. *Transitions to Sustainable Development: New Directions in the Study of Long Term Transformative Change*. New York: Routledge
5. Markard J, Raven R, Truffer B. 2012. Sustainability transitions: an emerging field of research and its prospects. *Res. Policy* 41:955–67
6. Van den Bergh, Jeroen CJM, Truffer B, Kallis G. 2011. Environmental innovation and societal transitions: introduction and overview. *Environ. Innov. Soc. Transit.* 1:1–23
7. Frantzeskaki N, Loorbach D. 2010. Towards governing infrasystem transitions: Reinforcing lock-in or facilitating change? *Technol. Forecast. Soc. Change* 77:1292–301
8. O'Riordan T. 1996. *Politics of Climate Change: A European Perspective*. London: Psychology Press
9. Raskin P. 2002. *Great Transition: The Promise and Lure of the Time Ahead*. Boston: Stockholm Environ. Inst.

10. Costanza R. 1992. *Ecological Economics: The Science and Management of Sustainability*. New York: Columbia Univ. Press
11. Kemp R. 1994. Technology and the transition to environmental sustainability. The problem of technological regime shifts. *Futures* 26:1023–46
12. Geels FW, en Kemp R. 2000. *Transities vanuit sociotechnisch perspectief*. Maastricht, Neth.: MERIT, Maastricht Univ.
13. Rip A, Kemp R. 1998. Technological change. In *Human Choice and Climate Change*, Vol. 2, ed. S Rayner, EL Malone, pp. 327–99. Columbus, Ohio: Battelle Press
14. Arthur WB. 1994. *Increasing Returns and Path Dependence in the Economy*. Ann Arbor, MI: Univ. Michigan Press
15. van den Bergh JCJM, Gowdy JM. 2000. Evolutionary theories in environmental and resource economics: approaches and applications. *Environ. Resour. Econ.* 17:37–57
16. O'Riordan T. 2001. *Globalism, Localism, and Identity: Fresh Perspectives on the Transition to Sustainability*. London: Earthscan
17. Van Asselt MBA, Rotmans J. 1996. Uncertainty in perspective. *Glob. Environ. Change* 6:121–57
18. Rotmans J. 1998. Methods for IA: the challenges and opportunities ahead. *Environ. Model. Assess.* 3:155–79
19. Loorbach D. 2007. *Transition Management: New Mode of Governance for Sustainable Development*. Rotterdam, Neth.: Erasmus Univ. Rotterdam Press
20. Voss J, Bauknecht D, Kemp R, eds. 2006. *Reflexive Governance for Sustainable Development*. Cheltenham, UK: Edward Elgar
21. Wolfram M. 2015. Conceptualizing urban transformative capacity: a framework for research and policy. *Cities* 50:121–30
22. Wittmayer JM, van Steenbergen F, Rok A, Roorda C. 2015. Governing sustainability: a dialogue between Local Agenda 21 and transition management. *Local Environ*. 21:939–55
23. Loorbach DA, Lijnis Huffenreuter R. 2013. Exploring the economic crisis from a transition management perspective. *Environ. Innov. Soc. Transit.* 6:35–46
24. van den Bergh JCJM. 2013. Economic-financial crisis and sustainability transition: introduction to the special issue. *Environ. Innov. Soc. Transit.* 6:1–8
25. Avelino F, Wittmayer JM. 2016. Shifting power relations in sustainability transitions: a multi-actor perspective. *J. Environ. Policy Plann.* 18:628–49
26. Grin J, Rotmans J, Schot J. 2011. On patterns and agency in transition dynamics: some key insights from the KSI programme. *Environ. Innov. Soc. Transit.* 1:76–81
27. Paredis E. 2013. *A Winding Road: Transition Management, Policy Change and the Search for Sustainable Development*. Ghent, Belg.: Ghent Univ.
28. Seyfang G, Haxeltine A. 2012. Growing grassroots innovations: exploring the role of community-based initiatives in governing sustainable energy transitions. *Environ. Plann. C* 30:381–400
29. Smith A. 2012. Civil society in sustainable energy transitions. In *Governing the Energy Transition: Reality, Illusion, or Necessity?*, ed. G Verbong, D Loorbach, pp. 190–202. New York: Routledge
30. European Environment Agency (EEA). 2015. *SOER 2015—the European environment—state and outlook 2015: a comprehensive assessment of the European environment's state, trends and prospects, in a global context*. Rep., EEA, Cph., Den. **http://www.eea.europa.eu/soer**
31. Organisation for Economic Co-operation and Development (OECD). 2015. *System innovation: synthesis report*. Rep., OECD, Paris. **http://www.innovationpolicyplatform.org/sites/default/files/general/SYSTEMINNOVATION_FINALREPORT.pdf**
32. Naberhaus M. 2011. *Effective strategies for the great transition: five leverage points for civil society organisations*. Conf. Pap., Smart CSO, London. **http://www.smart-csos.org/images/Documents/Smart%20CSOs%20Report%20english.pdf**
33. VROM. 2001. *Where There's a Will There's a World*. The Hague, Neth.: Ministry Hous., Spatial Plann. Environ. (VROM)
34. Gersick CJG. 1991. Revolutionary change theories: a multi-level exploration of the punctuated equilibrium paradigm. *Acad. Manag. Rev.* 16:10–36

35. Rip A. 1995. Introduction of new technology: making use of recent insights from sociology and economics of technology. *Technol. Anal. Strateg. Manag.* 7:417–31
36. Geels FW. 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Res. Policy* 31:1257–74
37. De Haan J. 2010. *Towards transition theory*. PhD thesis, Erasmus Univ., Rotterdam, Neth. **https://repub.eur.nl/pub/20593/**
38. Geels F. 2006. Major system change through stepwise reconfiguration: a multi-level analysis of the transformation of American factory production. *Technol. Soc.* 28:445–76
39. Turnheim B, Berkhout F, Geels F, Hof A, McMeekin A, et al. 2015. Evaluating sustainability transitions pathways: bridging analytical approaches to address governance challenges. *Glob. Environ. Change* 35:239–53
40. Geels FW, Schot J. 2007. Typology of sociotechnical transition pathways. *Res. Policy* 36:399–417
41. Kemp R, Schot J, Hoogma R. 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technol. Anal. Strateg. Manag.* 10:175–96
42. Van den Bergh J, Stagl S. 2004. Coevolution of economic behaviour and institutions: towards a theory of institutional change. *J. Evol. Econ.* 13:289–317
43. Geels F. 2005. Coevolution of technology and society: the multi-level perspective and a case study—the transition in water supply and personal hygiene in the Netherlands (1850–1930). *Technol. Soc.* 27(3):363–97
44. Raven R. 2007. Niche accumulation and hybridisation strategies in transition processes towards a sustainable energy system: an assessment of differences and pitfalls. *Energy Policy* 35:2390–400
45. Geels F, Raven R. 2006. Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003). *Technol. Anal. Strateg. Manag.* 18:375–92
46. Elzen B, Wieczorek A. 2005. Transitions towards sustainability through system innovation. *Technol. Forecast. Soc. Change* 72:651–61
47. Smith A, Voß J-P, Grin J. 2010. Innovation studies and sustainability transitions: the allure of the multi-level perspective and its challenges. *Res. Policy* 39:435–48
48. Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A. 2008. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. *Res. Policy* 37:407–29
49. Jørgensen U. 2012. Mapping and navigating transitions—the multi-level perspective compared with arenas of development. *Res. Policy* 41:996–1010
50. Hekkert MP, Suurs RA, Negro SO, Kuhlmann S, Smits R. 2007. Functions of innovation systems: a new approach for analysing technological change. *Technol. Forecast. Soc. Change* 74:413–32
51. Suurs RA. 2009. *Motors of Sustainable Innovation: Towards a Theory on the Dynamics of Technological Innovation Systems*. Utrecht, Neth.: Utrecht Univ. **https://dspace.library.uu.nl/handle/1874/33346**
52. van Raak R. 2016. *Transition policies: Connecting system dynamics, governance and instruments in an application to Dutch healthcare*. PhD thesis, Erasmus Univ., Rotterdam, Neth. **https://repub.eur.nl/pub/80061/**
53. Frantzeskaki N, Loorbach D, Meadowcroft J. 2012. Governing societal transitions to sustainability. *Int. J. Sustain. Dev.* 15:19–36
54. Shove E, Walker G. 2010. Governing transitions in the sustainability of everyday life. *Res. Policy* 39:471–6
55. Cohen MJ, Brown HS, Vergragt P. 2013. *Innovations in Sustainable Consumption: New Economics, Sociotechnical Transitions and Social Practices*. Cheltenham, UK: Edward Elgar
56. Cohen MJ, Szejnwald Brown H, Vergragt PJ, eds. 2017. *Social Change and the Coming of Post-consumer Society: Theoretical Advances and Policy Implications*. New York: Routledge
57. Tukker A, Emmert S, Charter M, Vezzoli C, Sto E, et al. 2008. Fostering change to sustainable consumption and production: an evidence based view. *J. Clean. Prod.* 16:1218–25
58. Coenen L, Benneworth P, Truffer B. 2012. Toward a spatial perspective on sustainability transitions. *Res. Policy* 41:968–79
59. Loorbach D, Avelino F, Haxeltine A, Wittmayer J, O'Riordan T, et al. 2016. The economic crisis as a game changer? Exploring the role of social construction in sustainability transitions. *Ecol. Soc.* 21:15
60. Konrad K, Truffer B, Voß J. 2008. Multi-regime dynamics in the analysis of sectoral transformation potentials: Evidence from German utility sectors. *J. Clean. Prod.* 16:1190–202

61. Beers PJ, Sol J, Wals A. 2010. *Social learning in a multi-actor innovation context*. Presented at Int. Farm. Syst. Assoc. Conf., Vienna, Austria, 3–7 July
62. Fuenfschilling L, Truffer B. 2014. The structuration of socio-technical regimes—conceptual foundations from institutional theory. *Res. Policy* 43:772–91
63. Brown RR, Farrelly MA, Loorbach DA. 2013. Actors working the institutions in sustainability transitions: the case of Melbourne's stormwater management. *Glob. Environ. Change* 23:701–18
64. Shove E, Walker G. 2008. Transition management and the politics of shape shifting. *Environ. Plann. A* 40:1012–14
65. Hendriks CM. 2009. Policy design without democracy? Making democratic sense of transition management. *Policy Sci*. 42:341–68
66. Meadowcroft J. 2009. What about the politics? Sustainable development, transition management, and long term energy transitions. *Policy Sci*. 42:323–40
67. Kern F, Howlett M. 2009. Implementing transition management as policy reforms: A case study of the Dutch energy sector. *Policy Sci*. 42:391–408
68. Voß J, Smith A, Grin J. 2009. Designing long-term policy: rethinking transition management. *Policy Sci*. 42:275–302
69. Avelino F. 2011. *Power in transition: empowering discourses on sustainability transitions*. PhD thesis, Erasmus Univ., Rotterdam, Neth. **https://repub.eur.nl/pub/30663**
70. Hoffman J. 2013. Theorizing power in transition studies: the role of creativity and novel practices in structural change. *Policy Sci*. 46:257–75
71. Pel B. 2015. Trojan horses in transitions: a dialectical perspective on innovation "capture." *J. Environ. Policy Plann.* 18:673–91
72. Loorbach D, Wittmayer JM, Shiroyama H, Fujino J, Mizuguchi S, eds. 2016. *Governance of Urban Sustainability Transitions: European and Asian Experiences*, Vol. 1. Tokyo: Springer
73. Frantzeskaki N, Castán Broto V, Coenen L, Loorbach D, eds. 2017. *Urban Sustainability Transitions*. London: Routledge
74. Jhagroe S, Loorbach D. 2015. See no evil, hear no evil: the democratic potential of transition management. *Environ. Innov. Soc. Transit.* 15:65–83
75. Arentsen M, Bellekom S. 2014. Power to the people: Local energy initiatives as seedbeds of innovation? *Energy Sustain. Soc.* 4:1–12
76. Späth P, Rohracher H. 2010. 'Energy regions': the transformative power of regional discourses on socio-technical futures. *Res. Policy* 39:449–58
77. Avelino F, Dumitru A, Longhurst N, Wittmayer J, Hielscher S, et al. 2015. *Transitions towards new economies? A transformative social innovation perspective*. Work. Pap. 3, TRANSIT
78. Haxeltine A, Wittmayer J, Avelino F, Kemp R, Weaver P, et al. 2013. *Transformative social innovations: a sustainability transition perspective on social innovation*. Presented Soc. Front. Next Edge Soc. Innov. Res., Nov. 13–14, Glasgow Caledonian Univ., London
79. Holling CS. 1973. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Syst.* 4:1–23
80. Gunderson L, Holling CS, eds. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington, DC: Island Press
81. Rockstrom J, Steffen W, Noone K, Persson A, Chapin FS, et al. 2009. A safe operating space for humanity. *Nature* 461:472–75
82. Galaz V, Biermann F, Crona B, Loorbach D, Folke C, et al. 2012. "Planetary boundaries"—exploring the challenges for global environmental governance. *Curr. Opin. Environ. Sustain.* 4:80–87
83. Haberl H, Fischer-Kowalski M, Krausmann F, Martinez-Alier J, Winiwarter V. 2011. A socio-metabolic transition towards sustainability? Challenges for another great transformation. *Sustainable Dev*. 19:1–14
84. Folke C, Hahn T, Olsson P, Norberg J. 2005. Adaptive governance of socio-ecological systems. *Annu. Rev. Environ. Resour.* 30:441–73
85. Krausmann F, Schandl H, Sieferle RP. 2008. Socio-ecological regime transitions in Austria and the United Kingdom. *Ecol. Econ.* 65:187–201
86. Haase D, Frantzeskaki N, Elmqvist T. 2014. Ecosystem services in urban landscapes: practical applications and governance implications. *Ambio* 43:407–12

87. Chapin III FS, Kofinas GP, Folke C, Chapin MC. 2009. *Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World*. New York: Springer-Verlag
88. Steffen W, Persson Å, Deutsch L, Zalasiewicz J, Williams M, et al. 2011. The Anthropocene: from global change to planetary stewardship. *AMBIO: A J. Hum. Environ.* 40:739–61
89. Österblom H, Gårdmark A, Bergström L, Müller-Karulis B, Folke C, et al. 2010. Making the ecosystem approach operational—Can regime shifts in ecological-and governance systems facilitate the transition? *Mar. Policy* 34:1290–99
90. Olsson P, Galaz V, Boonstra WJ. 2014. Sustainability transformations: a resilience perspective. *Ecol. Soc.* 19:1
91. Jessop B. 2003. Governance and metagovernance: on reflexivity, requisite variety, and requisite irony. In *Governance, as Social and Political Communication*, ed. H Bang, pp. 142–72. Manchester, UK: Manchester Univ. Press
92. Rhodes RAW. 1996. The new governance: governing without government. *Polit. Stud.* 44:652–67
93. Beck U, Giddens A, Lash S. 1994. *Reflexive Modernization: Politics, Tradition and Aesthetics in the Modern Social Order*. Stanford, CA: Stanford Univ. Press
94. Eising R, Kohler-Koch B. 1999. Introduction: network governance in the European Union. In *The Transformation of Governance in the European Union*, ed. B Kohler-Koch, R Eising, pp. 3–13. London: Routledge
95. Hooghe L. and Marks G. 2001. *Multi-level Governance and European Integration*. Oxford, UK: Rowman & Littlefield
96. Milward HB, Provan KG. 2000. How networks are governed. In *Governance and Performance*, ed. H Lynn, pp. 238–62. Washington, DC: Georgetown Univ. Press
97. Scharpf F. 1997. The problem solving capacity of multi-level governance. *J. Eur. Public Policy* 4:520–38
98. Voss JP, Bauknecht D, Kemp R, eds. 2006. *Reflexive Governance for Sustainable Development*. Cheltenham, UK: Edward Elgar Publ.
99. Loorbach D. 2010. Transition management for sustainable development: a prescriptive, complexity-based governance framework. *Governance* 23:161–83
100. Biermann F, Pattberg P. 2008. Global environmental governance: taking stock, moving forward. *Annu. Rev. Environ. Resour.* 33:277–94
101. Lemos MC, Agrawal A. 2006. Environmental governance. *Annu. Rev. Environ. Resour.* 31:297–325
102. Elkington J. 2006. Governance for sustainability. *Corp. Gov.* 14:522–29
103. Nooteboom S. 2006. *Adaptive Networks: The Governance for Sustainability*. Rotterdam, Neth.: Erasmus Univ. Rotterdam Press
104. Patterson J, Schulz K, Vervoort J, van der Hel S, Widerberg O, et al. 2016. Exploring the governance and politics of transformations towards sustainability. *Environ. Innov. Soc. Transit.* In press. **http://dx.doi.org/10.1016/j.eist.2016.09.001**
105. Wittmayer J. 2016. *Transition management, action research and actor roles: understanding local sustainability transitions*. PhD thesis, Erasmus Univ., Rotterdam, Neth. **http://hdl.handle.net/1765/94385**
106. Avelino F, Rotmans J. 2011. A dynamic conceptualization of power for sustainability research. *J. Clean. Prod.* 19:796–804
107. Fischer L, Newig J. 2016. Importance of actors and agency in sustainability transitions: a systematic exploration of the literature. *Sustainability* 8:476
108. Scholz RW, Spoerri A, Lang DJ. 2009. Problem structuring for transitions: the case of Swiss waste management. *Futures* 41:171–81
109. Wiek A, Binder C, Scholz R. 2006. Functions of scenarios in transition processes. *Futures* 38:740–66
110. Hisschemoller M, Hoppe R, Dunn WN, Ravetz JR, ed. 2001. *Knowledge, Power, and Participation in Environmental Policy Analysis*. New Brunswick, NJ: Transaction Publ.
111. Sondeijker S, Geurts J, Rotmans Tukker A. 2006. Imagining sustainability: the added value of transition scenarios in transition management. *Foresight* 8:15–30
112. Quist J, Vergragt P. 2006. Past and future of backcasting: the shift to stakeholder participation and a proposal for a methodological framework. *Futures* 38:1027–45
113. Nevens F, Frantzeskaki N, Gorissen L, Loorbach D. 2013. Urban transition labs: co-creating transformative action for sustainable cities. *J. Clean. Prod.* 50:111–22

114. Brown HS, Vergragt PJ, Green K, Berchicci L. 2004. Bounded sociotechnical experiments (BSTEs): higher order learning for transitions towards sustainable mobility. In *System Innovation and the Transition to Sustainability: Theory, Evidence, and Policy*, ed. B Elzen, FW Geels, K Green, pp. 191–222. Cheltenham, UK: Edward Elgar Publ.
115. Raven R, Van den Bosch S, Weterings R. Transitions and strategic niche management: towards a competence kit for practitioners. *Int. J. Technol. Manag.* 51.1:57–74
116. Bos J, Brown R. 2012. Governance experimentation and factors of success in socio-technical transitions in the urban water sector. *Technol. Forecast. Soc. Change* 79:1340–53
117. Loeber A, Van Mierlo B, Leeuwis C, Grin J. 2007. The practical value of theory: conceptualizing learning in the pursuit of a sustainable development. In *Social Learning Toward a More Sustainable World: Principles, Perspectives, and Praxis*, ed. A Wals, T Van der Leij, pp. 83–98. Wageningen, Neth.: Wageningen Acad. Publ.
118. Sol J, Beers PJ, Wals AE. 2013. Social learning in regional innovation networks: trust, commitment and reframing as emergent properties of interaction. *J. Clean. Prod.* 49:35–43
119. Grin J, Weterings R. 2005. *Reflexive monitoring of systems innovative projects: strategic nature and relevant competences*. Presented at Open Meet. Human Dimensions Global Environ. Change Res. Commun., 6th, Bonn, Ger., Oct. 9–13
120. Taanman M. 2014. *Looking for transitions: a monitoring approach to improve transition programmes*. PhD thesis, Erasmus Univ., Rotterdam, Neth. **https://repub.eur.nl/pub/77582**
121. Hendriks CM, Grin J. 2007. Contextualizing reflexive governance: the politics of Dutch transitions to sustainability. *J. Environ. Policy Plann.* 9:333–50
122. Voss J, Bauknecht D, Kemp R, ed. 2006. *Reflexive Governance for Sustainable Development*. Cheltenham, UK: Edward Elgar
123. Pahl-Wostl C, Downing T, Kabat P, Magnuszewski P, Meigh J, et al. 2005. *Transition to adaptive water management: The NeWater project*. NeWater Work. Pap., Inst. Environ. Syst. Res., Univ. Osnabrück. **http://nora.nerc.ac.uk/1018/**
124. Van der Brugge R, Rotmans J, Loorbach D. 2005. The transition in Dutch water management. *Reg. Environ. Change* 5:164
125. de Haan FJ, Rogers BC, Frantzeskaki N, Brown R. 2015. Transitions through a lens of urban water. *Environ. Innov. Sustain. Transit.* 15:1–10
126. Parto S, Loorbach D, Lansink A, Kemp R. 2007. Transitions and institutional change: the case of the Dutch waste subsystem. In *Industrial Innovation and Environmental Regulation: Developing Workable Solutions*, ed. S Parto, B Herbert-Copley, pp. 233–57. Tokyo: United Nations University Press
127. Van Eijck J, Romijn H. 2008. Prospects for Jatropha biofuels in Tanzania: an analysis with strategic niche management. *Energy Policy* 36:311–25
128. Van der Laak W, Raven R, Verbong G. 2007. Strategic niche management for biofuels: analysing past experiments for developing new biofuel policies. *Energy Policy* 35:3213–25
129. Späth P, Rohracher H. 2012. Local demonstrations for global transitions—dynamics across governance levels fostering socio-technical regime change towards sustainability. *Eur. Plann. Stud.* 20:461–79
130. Rohracher H. 2001. Managing the technological transition to sustainable construction of buildings: a socio-technical perspective. *Technol. Anal. Strateg. Manag.* 13:137–50
131. Schot J, Rip A. 1997. The past and future of constructive technology assessment. *Technol. Forecast. Soc. Change* 54:251–68
132. Schreuer A, Ornetzeder M, Rohracher H. 2010. Negotiating the local embedding of socio-technical experiments: a case study in fuel cell technology. *Technol. Anal. Strateg. Manag.* 22:729–43
133. Shove E, Walker G. 2007. CAUTION! Transitions ahead: politics, practice, and sustainable transition management. *Environ. Plann. A* 39:763–70
134. Meadowcroft J. 2011. Engaging with the politics of sustainability transitions. *Environ. Innov. Soc. Transit.* 1:70–75
135. Avelino F, Grin J, Pel B, Jhagroe S. 2016. The politics of sustainability transitions. *J. Environ. Policy Plann.* 18(5):557–67
136. Hendriks CM, Grin J. 2007. Contextualizing reflexive governance: the politics of Dutch transitions to sustainability. *J. Environ. Policy Plann.* 9:333–50

137. Kern F, Smith A. 2007. Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy Policy* 36:4093–103
138. de Gooyert V, Rouwette E, van Kranenburg H, Freeman E, van Breen H. 2016. Sustainability transition dynamics: towards overcoming policy resistance. *Technol. Forecast. Social Change* 111:135–45
139. Smith A, Kern F. 2009. The transitions storyline in Dutch environmental policy. *Environ. Polit.* 18:78–98
140. Van Der Loo F, Loorbach D. 2012. The Dutch Energy Transition project (2000–2009). See Ref. 2, pp. 220–50
141. Verbong G, Geels F. 2006. The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). *Energy Policy* 13:45–59
142. Rogge KS, Reichardt K. 2016. Policy mixes for sustainability transitions: an extended concept and framework for analysis. *Res. Policy* 45:1620–35
143. Kivimaa P, Kern F. 2016. Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Res. Policy* 45:205–17
144. Alkemade F, Hekkert MP, Negro SO. 2011. Transition policy and innovation policy: Friends or foes? *Environ. Innov. Societal Transitions* 1:125–29
145. Grin J. 2012. The politics of transition governance in Dutch agriculture. Conceptual understanding and implications for transition management. *Int. J. Sustain. Dev.* 15:72–89
146. Spaargaren G, Oosterveer P, Loeber A. 2013. *Food Practices in Transition: Changing Food Consumption, Retail and Production in the Age of Reflexive Modernity*. New York: Routledge
147. Geels F, Kemp R, Dudley G, Lyons G. 2011. *Automobility in Transition? A Socio-technical Analysis of Sustainable Transport*. New York: Routledge
148. Hoogma R, Kemp R, Schot J, Truffer B. 2004. Experimenting for sustainable transport: the approach of strategic niche management. *Technol. Anal. Strat. Manag.* 16(4):561–66
149. Schot J, Geels FW. 2008. Strategic niche management and sustainable innovation journeys: Theory, findings, research agenda, and policy. *Technol. Anal. Strateg. Manag.* 20:537–54
150. Kemp R, Loorbach D. 2003. Governance for sustainability through transition management. Presented at Open Meet. Hum. Dimensions Glob. Environ. Change Res. Commun., Montreal, Canada, Oct. 16–18. **http://sedac.ciesin.columbia.edu/openmeeting/side.html**
151. Kemp R, Rip A, Schot J. 2001. Constructing transition paths through the management of niches. In *Path Dependence and Creation*, ed. R Garud, P Karnoe, pp. 269–99. Mahwa, NJ: Lawrence Erlbaum
152. Loorbach D. 2014. *To Transition! Governance Panarchy in the New Transformation*. Rotterdam, Neth.: Dutch. Res. Inst. Trans., Erasmus Univ.
153. Nevens F, Frantzeskaki N, Gorissen L, Loorbach D. 2013. Urban transition labs: co-creating transformative action for sustainable cities. *J. Clean. Prod.* 50:111–22
154. Ernston H, Van der Leeuw S, Redman C, Meffert D, Davis G, et al. 2010. Urban transitions: on urban resilience and human-dominated ecosystems. *AMBIO: A J. Hum. Environ.* 39:531–45
155. Hess DJ. 2014. Sustainability transitions: a political coalition perspective. *Res. Policy* 43:278–83
156. Bosman R, Loorbach D, Frantzeskaki N, Pistorius T. 2014. Discursive regime dynamics in the Dutch energy transition. *Environ. Innov. Soc. Transit.* 14:45–59
157. Wittmayer JM, Schäpke N. 2014. Action, research and participation: roles of researchers in sustainability transitions. *Sustain. Sci.* 9:483–96
158. Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, et al. 2012. Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustain. Sci.* 7:25–43
159. Hadorn GH, Bradley D, Pohl C, Rist S, Wiesmann U. 2006. Implications of transdisciplinarity for sustainability research. *Ecol. Econ.* 60:119–28
160. Kallis G, Kerschner C, Martinez-Alier J. 2012. The economics of degrowth. *Ecol. Econ.* 84:172–80
161. Miller TR, Wiek A, Sarewitz D, Robinson J, Olsson L, et al. 2014. The future of sustainability science: a solutions-oriented research agenda. *Sustainability Sci.* 9:239–46
162. Wittmayer J, Schäpke N, Feiner G, Piotrowski R, van Steenbergen F, Baasch S. 2013. *Action research for sustainability: reflections on transition management in practice*. Res. Brief, InContext, FP7. **https://www.researchgate.net/profile/Niko_Schaepke/publication/262378898_Action_research_for_sustainability_-_Reflection_on_transition_management_in_practice/links/00b7d5378f4a31c5ad000000.pdf**

163. Funtowicz SO, Ravetz JR. 1993. Science for the post-normal age. *Futures* 25:739–55
164. Kates RW, Clark WC, Corell R, Hall JM, Jaeger C, et al. 2001. Environment and development—sustainability science. *Science* 292:641–42
165. Yarime M, Trencher G, Mino T, Scholz RW, Olsson L, et al. 2012. Establishing sustainability science in higher education institutions: towards an integration of academic development, institutionalization, and collaborations with stakeholders. *Sustain. Sci.* 7(1):101–13
166. Trencher G, Bai X, Evans J, McCormick K, Yarime M. 2014. University partnerships for co-designing and co-producing urban sustainability. *Glob. Environ. Change* 28:153–65
167. Loorbach D, Frantzeskaki N, Thissen W. 2011. A transition research perspective on governance for sustainability. In *European Research on Sustainable Development*, ed. C Jaeger, JD Tábara, J Jaeger, pp. 73–89. Berlin, Heidelberg: Springer
168. Köhler J, Whitmarsh L, Nykvist B, Schilperoord M, Bergman N, Haxeltine A. 2009. A transitions model for sustainable mobility. *Ecol. Econ.* 68:2985–95
169. Yücel G. 2010. *Analyzing transition dynamics: The actor-option framework for modelling socio-technical systems*. PhD Thesis, Delft Univ. Technol., Delft, Neth. **http://repository.tudelft.nl/islandora/object/uuid%3Aef6df5cc-ac64-4b33-bc05-3d6a0b98727d?collection = research**
170. Frantzeskaki N, Grin J, Thissen W. 2016. Drifting between transitions, the case of the Greek environmental transition in relation to the river Acheloos Diversion project. *Technol. Forecast. Soc. Change* 102:275–86
171. Wittmayer JM, Schäpke N. 2014. Action, research and participation: roles of researchers in sustainability transitions. *Sustain. Sci.* 9:483–96
172. Audet R. 2014. The double hermeneutic of sustainability transitions. *Environ. Innov. Soc. Transit.* 11:46–49