Chapter 2
Conceptual Grounds of Socio-Technical Transitions and Governance

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As for the future, your task is not to foresee, but to enable it.
Antoine de Saint Exupery

Abstract This chapter provides an overview of theorizing on technology change and socio-technical transition. The first contribution of the chapter is to clarify how distinct theoretical framework should be understood in the context of other related theorizing. The second contribution is to clarify the sources of theoretical tensions, and to resolve ambiguities in terms. This is important because tensions and ambiguities hinder the accumulation of an inter-subjective theoretical ground. We observe that sustainability transition research increasingly relies on process theorizing. It stresses the role of feedback mechanisms and systemic barriers as a new rationale for concerted strategy and policymaking. On the other hand, it does not answer the questions of which and how causal structures influence system behavior, e.g., in terms of reaching emission reduction targets in time and/or dynamical competitiveness. We have identified two reasons for this tension. First, sustainability transition research traditionally employs descriptive theorizing. Behavioral consequences remain obscure due to lacking causal propositions. Second, there exists a variety of categorization schemes that use ambiguous technical terms for describing linkages, processes, and performance characteristics. Consequently, we propose a standardization of system technical terms based on system dynamics methodology. This is important to facilitate a shared understanding on the factors and processes of (un-)desired transition trends. Further, we propose to apply system dynamics mapping tools to conceptualize socio-technical systems as a causal feedback system. This mapping approach provides the structural elements of critical behavior phenomena, like inertia, lock-in, and path creation, in socio-technical systems. We assume that this is particularly supportive for governance-based steering, because causal beliefs about effective governance structures are a necessary condition for the acceptance of concerted action programs in heterogeneous actor groups.

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S. Ulli-Beer (ed.), *Dynamic Governance of Energy Technology Change*, Sustainability and Innovation, DOI 10.1007/978-3-642-39753-0_2,

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2.1 Introduction

In this chapter we critically discuss conceptual grounds of technology change and sustainability transition research. Innovation researchers have to deal with a multi-faceted reality, therefore they develop *analytical perspectives* for building internally consistent theories that reduce the dynamical complexity in such a way that a "useful" picture emerges. A variety of analysis approaches have emerged, which shows a broadening in the problem framing and unit of analysis (Smith et al. 2010). Their common research interest is to describe the structure or performance of systems. In other words, they aim to clarify the factors and processes that explain the rate, direction and patterns of (radical) innovation adoption, diffusion and use. However, tensions between different theorizing approaches may arise depending on the chosen perspective, conceptualization, and terminology (Poole and Van de Ven 1989). While such tensions are confusing for (novice) researchers and practitioners, they also offer opportunities to advance sustainable transition theories, as the flourishing discussion in the literature shows (Edquist 2004; Hekkert et al. 2007; Bergek et al. 2008; Smith et al. 2010; Foxon 2011).

The overarching aim of this chapter is to enhance the clarity of the real world context and theoretical approaches of *energy technology change and socio-technical transitions*. We provide answers to the three guiding research questions:

- How should distinct theorizing be understood in the context of related theorizing?
- What are the sources of tensions and confusions between related theorizing?
- How can the tensions and ambiguities be resolved?

After providing a better understanding about the terms technology change, socio-technical transitions and governance, we elaborate distinct characteristics of different modes of theorizing. This provides the underlying logic for discussing the synopsis on theorizing on technology change and socio-technical transitions. We will specifically focus on the modus of theorizing and the applied technical terms to describe important factors and processes. Finally, we propose *a system dynamics perspective* that allows resolving some of the tensions and integrating insights from distinct theorizing.

We believe that this theoretical discussion is specifically helpful for novice innovation researchers that aim to develop theoretically grounded decision support tools for policy and strategy support in (messy) socio-technical problem situations.

2.2 The Real World Socio-Technical Governance Situation

> The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill. Albert Einstein, cited in (Van de Ven 2007: 71).

In this section, the real world challenge of the governance of sustainability transitions in socio-technical systems is elaborated. A better understanding of the specific challenges helps researchers to identify and integrate the relevant knowledge concerning technology change and sustainability transition research for policy and strategy making.

Consequently, the perspective taken in this chapter and throughout the book departs from a managerial situation of entrepreneurs and policymakers at the local level that proactively try to respond to global changes, such as climate change. Motivations for their actions arise not only from the established action paradigms of securing competitive advantages or economic growth, but also from enhancing resource productivity and from mitigation opportunities of global threads (Porter and Van der Linde 1995; Smith et al. 2010). These motivations come along with additional challenges, such as the establishment of new action paradigms within socio-technical systems. These may induce broader change within existing regimes of science and technology, industries, markets, and politics, but also the built environment (Geels and Schot 2007). This means that segmentation and decentralized decision making in socio-technical systems increases the complexity of the management task.

This creates a specific management situation. It turns from a well-structured problem situation that is amenable by well-known problem-solving technologies (in the broadest sense) into a messy problem situation. Such a situation is defined as "a dynamic situation that consists of complex systems of changing problems that interact with each other" (Ackoff 1979: 99). Müller, Grösser et al. (see Chap. 4) specify the messy action context of a socio-technical transition challenge as a societal problem situation. They characterize such transition challenges as "*highly fragmented situations, where it may not be clear what exactly the problem is, what kind of actors are involved in it, and who is responsible for addressing the problem. In particular, fragmentation means that actors in the problem situation may not be aware that they are participants in a societal problem situation*" (Müller et al. 2012: 498). This messy transition challenge also involves dynamic decision-making tasks. These are tasks that require managing rates and states of a system, such as selling/scrappage rates of (energy-efficient) cars and its corresponding fleet stock, or the decay and renovation rate of the stock of buildings with the objective to achieve a cost-effective CO_2 emission reduction trajectory. Experimental research and practice has shown repeatedly that such tasks are managed with low performance results, yielding costly, unsustainable, or undesired outcomes (Sterman 1989; Sterman 1994; Diehl and Sterman 1995; Moxnes 2004). The poor performance is explained by misperception of circular causalities (i.e., biased perceptions of delays, nonlinearities, or feedback complexities) that results in deficient management rules. Such a messy and dynamic complex situation hampers the deployment of eco-innovations and policy making. It calls for the development of adequate perspectives, frameworks and analysis methods for elaborating helpful guidance and decision support for the concrete problem situation (Sterman 2011).

Such tools should help entrepreneurs and policymakers to overcome their own misperception when dealing with dynamical decision tasks. Specifically, they should give guidance in dealing with systemic barriers and drivers, such as historically grounded lock-in effects and path creation toward a greener economy. Therefore, the tool should be applicable for strategy and policy making in the concrete action context, i.e., support the discussion of competitive advantages and compliance with CO_2 emission targets.

2.3 The Notion of Socio-Technical Transition and Governance Dynamics

The overarching topic of the book is summarized by the title: *governance dynamics of energy technology change toward more sustainable futures: analyzing and substantiating socio-technical transitions*. In this subsection we elaborate the understanding of the applied terms.

Technology change: With the notion technology change, we refer to the rate and direction of technology development and its economic impact. Relevant theorizing on technology change can be found within the disciplinary fields of technology and innovation management, industrial dynamics, and evolutionary economics, as well as the systems of innovation literature. The technology change literature is strongly linked to economic growth and competition issues.

Socio-technical transition: Socio-technical transition refers to reconfiguration processes between technology development and broader adjustment processes in science, industry, markets, policy, and culture (Geels and Schot 2007) that are necessary for the creation of new trajectories (Geels 2002; Geels and Schot 2007). Socio-technical system encompass the subsystem of production, diffusion and use of technology (Geels 2004). In contrast to technology change research addressing traditionally economic growth issues, the broader focus of research on socio-technical transition towards sustainability is interested in understanding how shifts in societal undesired trajectories of technological developments towards more sustainable trajectories come about in sectors such as transportation or housing (Kemp et al. 1998). This specific kind of research is also called sustainability transition research. The term sustainability indicates the normative quest of the direction and rate of change. It explicitly acknowledges the need to secure all three aspects in the socio-technical governance task, i.e., economical, ecological and societal aspects.

Governance: In the literature, the notion governance is described in many different ways and often used as an imprecise term that is related to policy interventions and institution building by the government (Meadowcroft 2007; Florini and Sovacool 2009). Government is a crucial but not the only means through which governance or coordination is achieved between actors. According to Florini and Sovacool (2009), "governance refers to any of the myriad processes through which a group of people set and enforce the rules needed to enable that group to achieve desired outcomes" (5240). In the context of societal problem situations, arrangements of public and private actors for solving societal problems are referred to as social-political governance (Kooiman 2000). Meadowcroft (2007) applies the notion "governance for sustainable development." He refers it to socio-political processes and interactions between public authorities, private business, and civil society oriented toward the attainment of sustainable development. It is a form of long term 'societal self-steering' that is goal directed and involve the coordination of activities of decentralized actors. Meadowcroft (2007) emphasizes that "a critical component of the steering involved in governance for sustainable development are the societal interactions which can help define 'clear goals' and develop better causal theories" (307). Because of this orientation on societal learning within governance, the term interactive or reflective governance is used (Hendriks and Grin 2007; Walker and Shove 2007). Voss et al. (2009) refers to the design of transition management as a promising mode of reflexive governance and long-term policy planning.

In our book we use the term governance in reference to socio-technical steering mechanisms understood in the sense of (circular) causalities, which coordinate the interactions of multiple actor groups or subsystems, as stated in Chap. 1. We assume that intertwined circular causalities between action rules control the power of actor groups with similar values and beliefs, the development of their resources, technologies, product markets, and infrastructures. Discrepancies between desired and effective system states create pressure for corrective actions within the socio-technical system; however, such purposeful responses may be overruled by historically established steering mechanisms and actor groups. This creates systemic resistance to change and results in undesired path dependencies and lock-in.[1] Not only purposeful interventions by the government and other actor

[1] Path dependence refers to self-reinforcing processes that accelerate the development direction within a system. Lock-in refers to a historically evolved system state that can only be changed with great effort.

groups to achieve a desired outcome are considered, but also counteracting steering mechanisms, which reflect power asymmetries and path dependence in the system.

The term *governance dynamics* refers to both the variation in socio-technical steering mechanisms and its direct or indirect influence on measurable trajectories of change, such as CO_2 emission trajectories. For example, discrepancies between desired and effective CO_2 emission rates from transportation exert pressure on the guiding rules of actor groups to pay more attention to environmental attributes in the decision-making process.

With this understanding, we emphasize structural and behavioral causalities of governance. In this manner, we relate micro-scale activities to changes over time in selected system indicators. This is a linkage that has not gained much attention in the literature about governance in general, and about governance of socio-technical transitions in particular.

2.4 Heterogeneity in Theorizing

Synopsis: In order to address the first research question, "How should distinct theorizing be understood in the context of related theorizing?" we provide a synopsis about relevant theorizing. The focus is on theory-building approaches in the technology change and sustainability transition literature that characterize important factors and processes of governance dynamics in socio-technical transitions. For our synopsis, we have selected illustrative and most important stepping stones that address aspects of competitive ability and sustainability transitions. This means that we have not considered all research that enhances the understanding of important determinants. An encompassing account of the different theoretical approaches is beyond the scope of this work. Thematically focused reviews can be found in the literature (e.g., Garcia and Calantone 2002; Jordan 2008; Markard and Truffer 2008; Coenen and Díaz López 2010; Smith et al. 2010; Markard et al. 2012). We acknowledge that we need to remain sensitive to more peripheral and new research lines within the broad field of sustainability transition studies. Here, we would like to emphasize specifically the new literature on determinants of eco-innovations that are based on panel data models and analysis (e.g., Cainelli et al. 2011; Horbach et al. 2012; Kesidou and Demirel 2012).

In our synopsis we give a brief idea about the content and scope of the selected perspectives. We show how theory development has increased the variety in the used perspectives and terminology for explaining the determinants of innovation, technology change, and sustainability transitions. We are interested in better understanding the sources of variety in used technical terms (i.e., factors, structure, elements, processes, forces, dynamics, interactions, alignments, feedback, motors, functions). How are the technical notions used in theorizing? How are determinants of innovation systems, transitions, and performance conceptualized? In this manner the reader may become confused concerning the variety of terms. But this is exactly the main argument of our contribution: The conceptual ground of socio-technological transition is confusing, specifically for the novice innovation researcher. Our synopsis should provide an orientation and facilitate the selection of further literature.

Modes of theorizing: In order to better understand the different approaches to theorizing in socio-technical transitions, some features of theorizing need to be distinguished. It provides the basis for answering the second research question, "What are the sources of tensions and confusions between related theorizing?"

Descriptive theory: Conceptual frameworks and analysis heuristics that do not specify causal relationships between concepts are not considered explanatory theory but descriptive theory. Descriptive theory aims at improving categorizing schemes in order to better identify the relevant attributes of a phenomena (Christensen 2006).

Explanatory theory: Explanatory theory formulates assumptions with theoretical terms (often based on categorizing schemes) about relationships, and conditions when they apply (Van de Ven 2007). Explanations may be provided at different levels of abstraction using theoretical or observable terms. Theoretical terms (i.e., concepts and constructs) allow a higher level of abstraction and are used to formulate grand and middle range theories. Derived statements about relationships are termed propositions. Observable terms are variables that allow testing hypotheses derived from operational theorizing. An adequate understanding of causal relationships is important to derive policy or strategy implications for action managers (Christensen 2006).

Van de Ven (2007) highlights two modes of scientific reasoning: *(1) variance theorizing* and *(2) process theorizing*. Variance theorizing focuses on variance in factors. It is based on the scientific logic of answering questions like, "What are the antecedents or consequences of the issue?" (145). Variance is explained in terms of relationships among independent and dependent variables or concepts.

Process theorizing applies a different theory-building perspective that focuses on changes over time. It asks questions like, "How does the issue emerge, develop, grow, or terminate over time?" (145). Outcomes are explained by sequences of events. Consequently, a process analysis investigates sequences of change and how they occur. An often-used process analysis method is the narrative approach, which uses a conceptual framework to describe how things develop and change. Another applied process approach is based on event analysis. Actions and activities are classified to a category of concepts or variables that are deemed relevant to understand variation in some outcome criteria.

Differentiating between these distinct modes and approaches of scientific reasoning is important to understand the variety in theory and term conceptions. Also, it helps to classify why and how different findings of theorizing relate to each other, i.e., to understand when they are complementary rather than competing.

2.4.1 Disciplinary Perspectives on Technology Change

There exists a wealth of theorizing on technology change and it has a 76-year-long history (Garcia and Calantone 2002). Specific determinants (e.g., factor prices, knowledge generation, and diffusion), characteristics of innovation (e.g., incremental and radical, disruptive and sustaining innovation) and impact of technology change (e.g., creative destruction of firms, economic growth, and environmental change) have been researched from different perspectives. These include supply, demand, or organizational perspectives, as well as evolutionary perspectives on technology change (Box 2.1).

Supply side or demand side perspectives: One prominent innovation model for explaining technology (supply) push innovation is the so-called linear or pipeline model. Innovation is explained by a linear succession of basic research that generates new knowledge that leads to new applied research, resulting in invention, prototyping, and development, and eventually to innovation with a successful business model that allows widespread diffusion. This innovation model was guiding the Manhattan project and many other technological innovations, particularly during and after the World War II era (Rosenbloom 1981; Weiss and Bonvillian 2009). The demand side perspective highlights innovations processes that are induced from the economic or selection environment (Ruttan 2001). It assumes that changes in the direction of technology development are caused by changes in the markets (e.g., increasing or decreasing factor prices) or policy environment (e.g., standard setting). It has been often applied to theorize on innovation in agricultural development.

Firm- and industry-level theorizing: Early on, the importance of linking technology management to further arenas of organizational development has been emphasized (Rosenbloom 1981). This includes theorizing on the relationship between technological dominant designs and innovation, as well as organizational change, competition of firms, and whole industries (Abernathy and Utterback 1978; Abernathy and Clark 1985; Tushman and Anderson 1986; Freeman and Perez 1988; Utterback 1994, 1996; Christensen and Rosenbloom 1995; Christensen 2002; Furman et al. 2002).

For example, the management of technology and innovations has been investigated at the firm level as an important determinant of competitive advantage (Utterback 1971; Cohen and Levinthal 1990; Adner 2006). Likewise, technology change became a very important topic for whole industries, because it has the capacity to disrupt the leadership structure of the industry and destroy big companies (Henderson and Clark 1990; Utterback and Suárez 1993; Utterback 1996; Adner 2002; Christensen 2006). Utterback (1994, 1996) specifically highlights the role of dominant product designs and technological innovations that imply "changes in system relationships" in the industry. He argues that, "architectural knowledge of products tends to become embedded in the structure and information-processing procedures of established organizations" (195). Critical are discontinuities that break market and manufacturing linkages and call for different kinds of business models (Utterback 1994, 1996; Christensen 2006). In sum, the literature emphasizes that specific characteristics of technological innovations and associated business models (e.g., incremental, radical, sustaining, or disruptive innovation) have distinct impacts, even on economic cycles (Freeman and Perez 1988; Henderson and Clark 1990; Christensen 2006).

Most of the theorizing described above went through the phase of descriptive theory building with different categorization schemes on characteristics of innovation and degree of innovativeness of a product, firm, or industry (Garcia and Calantone 2002). Eventually, disruption theory, as an example, entered the phase toward explanatory process theorizing, and the identification of the causal mechanism between technological innovation and the success or failure of leading companies (Christensen 2006). Newer panel data model and analysis specifically focus on the determinants of environmental innovations and firm-level performance (e.g., Horbach et al. 2012; Kesidou and Demirel 2012).

Endogenous variety creation: Dosi (1982) has suggested a micro-level framework of technology change that offers an endogenous explanation of paradigm changes in technology development; it accounts for incremental and radical technological change processes. In this, it explains how changes in the direction of technology change come about in the sense of a "mutation generating" mechanism. Radical changes in the direction of technological progress are attributed to paradigm change in the search processes. Important determinants are "scientific advances, economic factors, institutional variables and unsolved difficulties of established technological paths" (147). Incremental improvements follow the same search paradigm and therefore follow the established improvement trajectories.

Selection processes: Dosi's interpretation of technology change complements evolutionary economic models of technology change pioneered by Nelson and Winter (1977, 1982). They developed formal economic models with endogenous processes of technological change where the economic and social environments select between both the direction of mutations and the mutations themselves (Dosi 1982). Evolutionary thinking, with the core concepts of variation, selection, and differential replication, has become an important research field to better understand dynamics of changes in economies. In evolutionary economics modeling, innovation processes are conceptualized as the main driver of diversity creation in technology and practice (variation). Competition, regulations, and institutions are understood as mechanisms of selection. Imitation behavior is associated to differential selection. Eventually, different formal modeling approaches have been elaborated to analyze the outcome of these interacting processes (Safarzynska and Van den Bergh 2010). The potential of evolutionary modeling approaches to contribute to socio-technical transition theorizing has been highlighted more recently (Safarzynska et al. 2012).

Evolutionary economic modeling is an example of formal explanatory theorizing on a rather abstract level. It offers formal theorizing on causal mechanism and system behavior development over time. It has the potential to test propositions about micro-level processes and macro-level behavior.

Behavior patterns of technology change: With the growing importance of environmental and global changes, a kind of paradigm change toward a dynamic perspective on eco-technology change can be observed (Porter and Van der Linde 1995; Grübler 1998; Grübler et al. 1999b; Grübler et al. 2002). Grübler (1999a) provides ample empirical evidence that technological choices have long-term impact on the characteristics of industrial societies and the natural environment. Based on long-term historical analyses of time series, he identifies stylized stages of technological development and typical characteristics as a basis for the improvement of technological change modeling. In Table 2.1, six stages in the life cycle of a technology are differentiated: invention, innovation, niche market commercialization, pervasive diffusion, saturation, and senescence. For each stage, key mechanisms and measures (cost, market share, learning rates) are identified that relate its finding to extant technology change research. He concludes that, despite the extant wealth of technology change research, it remains an important area of research to elaborate processes of radical technological changes endogenously. This is deemed important to improve economic modeling approaches and to provide guidance on how to deploy the opportunities of eco-technology change (Grübler et al. 1999; Grübler et al. 1999).

This line of theorizing is an exemplar of process theorizing on behavior characteristics and underlying causal mechanisms. It provides both conceptual as well as more operational input to formal economic modeling approaches.

In summarizing this synopsis on technology change theorizing, we recognize that theorizing has advanced from, initial descriptive categorizing to explanatory theorizing. Also, variance theories have been complemented with process theories. Those either focus on behavioral sequences, on causal mechanisms, or even on proposition about what causal mechanisms explain observed behavior patterns over time. Hence, it is noteworthy that changes over times concerning structural relationships and system behavior aspects are addressed by the term dynamics of innovation in industries (Utterback 1994, 1996). Figure 2.1 illustrates stylized behavior patterns during phases of technology change that have been identified by firm- and industry-level theorizing. Most interesting is the number of firms that exhibit a boom-and-bust pattern during the stages of niche market commercialization and pervasive diffusion of radical (or disruptive) innovations.

Due to field specific boundaries, different levels of abstractions, and analysis, there exists a heterogeneous understanding about core determinants (either as factors or linkages between factors) of technology change. This may hinder the advancement of more formal modeling and operational theorizing approaches. In addition, the integration of this extant knowledge into theorizing on sustainability transition may be hampered.

Table 2.1 Stylized stages of technological development and typical characteristics (Adapted from Grübler et al. 1999a: 249)

Stage	Mechanisms	Cost	Market share	Learning rate
Invention	Idea & knowledge generation, breakthroughs; basic research	Difficult to attribute to a particular idea/product	0 %	Hard to measure
Innovation	Applied research, development, and demonstration (RD&D) projects	High, increasingly focused on particular, promising products	0 %	Hard to measure, high in learning (e.g.,> 50 %)
Niche market commercialization	Identification of special niche application; investments in field projects; close relationships between suppliers and users, learning by doing	High, but declining, with standardization of production	0–5 %	20–40 %
Pervasive diffusion	Standardization and mass production; economies of scale; building of network effects	Rapidly declining	5–50 % Rapidly rising	10–30 %
Saturation	Exhaustion of improvement potentials and scale economies, arrival of more efficient competitors into market; redefinition of performance requirements	Low, sometimes declining	Up to 100 %	< = 0 % severe competition
Senescence	Domination by superior competitors; inability to compete because of exhausted improvement potentials	Low, sometimes declining	Declining	< = 0 % severe competition

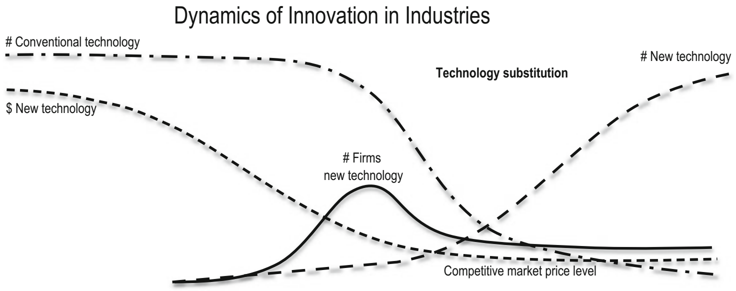

Fig. 2.1 Stylized behavior patterns of technology change in industries

Box 2.1: Definitions of Distinct Characteristics of Innovations

Definitions of important terms: In the literature, distinct innovation notions are used with often differing understanding (e.g., van den Hoed 2007). For our short overview, we refer to the original definitions of the key authors in the field.

Dominant design: "A dominant design embodies the requirements of many classes of users of a particular product, even though it may not meet the needs of a particular class to quite the same extent as would a customized design" (Utterback 1994, 1996: 25).

Incremental and radical innovations: "Incremental versus radical innovations can be reinterpreted in terms of 'normal' technical progress as opposed to new emerging 'technological' paradigms" (Dosi 1982: 158).

Sustaining innovation: "A sustaining innovation targets demanding, high-end customers with better performance than what was previously available. Some sustaining innovations are the incremental year-by-year improvements that all good companies grind out. Other sustaining innovations are breakthrough, leapfrog-beyond-the-competition products. It doesn't matter how technologically difficult the innovation is... Because this strategy entails making a better product that they [incumbents] can sell for higher profit margins to their best customers, the established competitors have powerful motivations to fight sustaining battles. And they have the resources to win" (Christensen 2003: 34).

Disruptive Innovations: "Disruptive innovations, in contrast, don't attempt to bring better products to established customers in existing markets. Rather, they disrupt and redefine that trajectory by introducing products and services that are not as good as currently available products. But disruptive technologies offer other benefits – typically, they are simpler, more convenient, and less expensive products that appeal to new or less-demanding customers" (Christensen 2003).

2.4.2 Systemic Perspectives on Sustainability Transitions

In the last three decades, research on *innovation systems* evolved around issues of technology change, economic growth, competitiveness, and sustainability transitions. Smith et al. (2010) explains the development of innovations studies on sustainability transitions as adjustments of analytical frameworks to the broadening of the problem framing – from clean technologies to industrial ecology, and to system innovation for sustainability. This development has been inspired by different research strands that include research on technological paradigms (e.g., Dosi 1982), on technological regimes (e.g., Nelson and Winter 1977), complex system research (e.g., Kauffman 1995) and national innovation systems research (e.g., Freeman 1988), as highlighted by Markard et al. (2012). The authors have identified the following four core research strands in the field of sustainability transitions studies: transition management (TM), strategic niche management (SNM), multi-level perspective (MLP) and technological innovation system (TIS). The authors also highlight that, for the maturation of the field of sustainability transitions studies, it becomes important to reach out beyond these approaches.

In this subsection, we intend to give a brief overview on the content and scope of most relevant systemic school of thoughts on technology change and sustainability transition, being the NIS (national innovation systems), TIS, TM and SNM, and the MLP approaches. In particular, we are interested in understanding how "determinants" of innovation system transitions and performance are conceptualized and what "system technical" notions are used. To remind, we neither intend to provide a detailed account of each approach, nor do we mean to give a systematic comparison of the approaches. These kinds of review can be found in the literature (e.g., Coenen and Díaz López 2010).

National systems of innovations (NIS): Since Freeman (1987, 1996), who first developed the system perspective to study conditions of innovations in nations, many innovation researchers have found the system perspective useful for studying *structures* and *processes* of innovations. Eventually, different systems of innovation have been defined depending on the specific scope and focus of analysis (e.g., national, sectoral, regional, technological, or socio-technical systems). The focus of a system perspective emphasizes *interactions* between technology, actors, institutions, and activities beyond the boundary of the firm (Geels 2004).

Freeman (1987) coined and defined the term national system of innovation as *"the network of institutions in the public and private sectors whose activities and interactions initiate, import, and diffuse new technologies"* (1987: 1). With the term activities, he refers to education, training, production engineering, design, and quality control, as well as R&D. These activities are organized by institutional arrangements, such as research councils, national R&D labs, or universities (Freeman 1995). Edquist (2004) provides a broader and more general definition of (national) systems of innovation. He argues that they encompass "all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovation." He points out that, at the present state of the art, the determinants of innovation are not understood systematically and in detail. Therefore, all factors that influence innovation processes should be included. This has laid the ground for further NIS research that focuses on the broader contextual factors and relationships that support technological change. For example, the "triple helix" of the university-industry-government relationship has been focused on as an important contextual relationship that supports innovation and economic growth (Etzkowitz and Leydesdorff 2000; Kim, Kim et al. 2012). Recent research has focused on factors that explain distinct patterns of technology-based sectoral change (Dolata 2009). The *transformative capacity* of a new technology has been suggested as one factor that describes the technology-based pressure for change. The complementary factor is the *sectoral adaptability* that accounts for the variance in the ability of social subsystems (e.g., institutions and actors) to anticipate and proactively manage technology pressure.

These innovation system approaches provide a broader perspective on factors and interactions (including institutions that organize different domains of activities) in support of technology-based entrepreneurship. In this, they enhance the understanding of effective structures in innovation systems concerning competitiveness. They offer a snapshot understanding of the structure. Therefore, the traditional innovation system approach may be considered as multi-dimensional variance theory. It does not address dynamic aspect, neither concerning the evolution of structures nor system behavior.

Technological innovation system (TIS): A specific focus on technological niche development has been suggested by the technological innovation system approach (Jacobsson and Bergek 2004; Hekkert et al. 2007; Bergek et al. 2008). It aims at better understanding the processes and their dynamics in the buildup of an innovation system.

This scholarship assumes that the innovation system around a technology is an important determinant of technological change. It postulates that the development of specific innovation system functions in chronological sequences is required for a successful development and deployment of cleaner technologies. Examples of such functions are entrepreneurial activities, knowledge development, knowledge diffusion, guidance of search, market formation, resource mobilization, and creation of legitimacy (Hekkert et al. 2007). A weak functional achievement or a mismatch between the achievements of different functions may explain an unsuccessful setup of an innovation system that accounts for eco-innovation failure.

This strand of research tries to identify patterns of reinforcing interactions between the functions, named motors that foster the development of the functions. With their approach, they provide a process framework about dynamics in structures and system behavior. It has the characteristics of a conceptual description framework, but does not yet qualify as a causal explanation for the emergence of structure and system behavior. It does not yet suggest consistent causal explanations about structural conditions that reinforce or hinder the performance of functional achievements. Any institution- and actor-specific dimensions are missing, as well as causal incentive or pressure concepts (Coenen and Díaz López 2010).

Strategic niche and transition management (SNM&TM): Transition management researchers use conceptions such a technological and market niches and how they enable shifts in socio-technical regimes (Kemp et al. 1998; Rip and Kemp 1998; Rotmans et al. 2001). The notion socio-technical regime has been developed in reference to the Nelson and Winter's (1982) technological regime notion. But it extends the narrow technological regime concept and includes interacting processes between heterogeneous institutions, a network that "creates the structural patterns that shape innovation and creates trajectories of social development" (Smith et al. 2010: 440).

The transition management approach particularly emphasizes strategic envisioning that supports goal-oriented modulation. The research focuses on steering from within, which refers to niche-internal processes that include networking, learning, and visioning. It can be applied as an analyses framework to describe how local (P&D) projects and global rule-sets guide actors' behavior. Transitions are described in terms of forces, interactions between niche internal and external processes (Schot and Geels 2008). The SNM literature also provides practical guidelines and tools for implementing such a governance approach (Kemp et al. 2007).

The TM approach offers a dynamic framework that enhances the understanding of system behavioral characteristics by classifying different phases of transitions (i.e., predevelopment, takeoff, breakthrough, and stabilization). Rotmans et al. (2001: 19) point out that "a transition is the result of long-term developments in stocks and short-term developments in flows." This understanding, together with the focus on structural processes, may provide a first step toward the formulation of a process theory that links structural aspects to system behavioral characteristics.

Multi-level perspective (MLP): Gradually, research on transition management resulted in the multi-level perspective (Rotmans et al. 2001; Geels 2002, 2005, 2010). It focuses on changes in institutional structures and actor networks over time. This approach distinguishes three analytical levels: niches, regimes, and landscape. The notion socio-technical regime refers to stable actor networks with well-aligned rules within and between different regimes, e.g., technological, scientific, industrial, market, governmental, and cultural regimes (see also Box 2.2). It describes the dominant modus operandi for realizing a societal function, such as housing or transportation. The dominant regime structures explain incremental change and path dependence within the socio-technical system, including also material artifacts and production resources.

Niches are protected spaces with flexible actor groups and rules. This setting explains how radical innovation can emerge and how variety is created. The landscape concept describes the external environment, which cannot be directly influenced by niche or regime actors (e.g., macro-political developments, cultural trends, and macro-economics), but may create pressure for change on the socio-technological regime. The main argument of the MLP approach is that alignment processes between and within the three levels account for both a transition from one system to another and stable trajectories. However, distinguishing context dimensions that differentiate successful transition from delayed/hindered are not yet consistently elaborated. Complementary frameworks provide further descriptive power that focuses on distinct characteristics of niches and regimes (Smith and Raven 2012).

A specific aspect of the MLP framework needs to be highlighted. It explicitly refers to the concept of reflexive agency and structure, which points to the relevance of actor-rule system dynamics for transitions (Giddens 1984; Burns and Flam 1987). The general characteristic of this conception is a feedback process that defines structures of actor networks and rule systems as both the medium and product of action. Based on this rationale, Geels (2004) suggests differentiating between the socio-technical system (i.e., material artifact, knowledge, capital, labor, and cultural meaning) and the actors and institutions (i.e., rules). The rules and activities of actors control how these resources are deployed. A drawback of the encompassing narrative of socio-technical transition is the lack of a theoretical micro-foundation for actor behavior; i.e., driving forces of eco-innovations within firms are not explicated.

In summary, we see that, up to date, a variety of conceptual frameworks are available to support the analysis of socio-technical transitions. This poses a challenge for the application selection of a theoretical perspective for a specific real world problem situation and the accumulation of a consistent knowledge stock. In a systematic literature review, Coenen and Díaz López (2010) have identified substantial conceptual differences between sectoral innovation systems, technological innovation systems and the MLP approach on socio-technical systems. Their systematic comparison reveals conceptual differences regarding the delineation of system boundary, and the conceptualization of actors, networks, institutions, and knowledge. Also, they point out tradeoffs between static perspectives and dynamic perspectives concerning the focus on system structure and system behavior. They conclude that these differences hinder knowledge integration for the investigation of drivers and barriers of sustainability transitions and improved competitiveness in socio-technical systems.

Box 2.2: Definition of Socio-Technical Regime

Definition of socio-technical regime: Kemp et al. (1998) have explicated their first definition of a technological regime as: "... the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that make up the totality of technology." They explain that they refer to rules and beliefs, which "... guide (but do not fix) the kind of research activities that companies are likely to undertake, the solutions that will be chosen and the strategies of actors (suppliers, government and user)." Those are "...embedded in engineering practices and search heuristics with the rules of the selection environment" (182). Later, this understanding has been applied to describe socio-technical regimes.

2.4.3 Governance of Technology Change and Sustainability Transitions

Corresponding with theorizing on technology change and sustainability transitions, theorizing on rationales of policy interventions in support of desired development trajectories has been advanced.

Market failures rationales: The rational for policy intervention in support of (eco-) innovations and environmental protection are traditionally based on the economic arguments of externalities or market failures. These are private costs of actors or public benefits that are not compensated by price mechanisms and are called market failures.

R&D and innovation policies are based on the existence of *positive externalities of knowledge creation*, or knowledge spillovers. Knowledge can easily be copied without compensating the inventor or innovators for the costs of creation. Therefore, there emerge asymmetries between private and social returns of innovation. The incentives to private firms to invest in innovations remain suboptimal for the economy (Arrow 1962).

Environmental policies are based on both the existence of negative externalities in respect of uncompensated harmful impact on the environment (Pigou 1932) and positive externalities (e.g., clean air and noise reduction).

These neo-classical economic rationales of policy interventions are complemented by rationales of "increasing returns" that create path-dependent or lock-in externalities (Arthur 1989; Arthur 1994; Arrow 2000; Unruh 2000; Unruh 2002; Unruh and Carrillo-Hermosilla 2006). They emphasize that those policies are more efficient, which influences the natural development of economic structures than those which enforces a static outcome (Arthur 1999). Jaffe et al. (2005) differentiate three different kinds of increasing returns that are relevant for the adoption and diffusion of green technologies: (1) *learning-by-using* in the demand side refers to information feedback processes between adopters and potential adopters about the "utility" of the new eco-technology; (2) *learning-by-doing* in the supply side refers to decreasing cost with increased experience; and (3) *network-externalities* arise if the utility of a product increases with increasing adoption of complementary products or infrastructures.

In addition to failures of product markets, capital markets for funding technology development are also characterized by failures. These are related to uncertainty about the returns on investment and information asymmetries about the potential of a technology.

These different kinds of policy rationales and reinforcing interactions of market failures imply the need of a concerted policy-portfolio that aims to stimulate technology development and diffusion as well as the internalization of environmental impacts (Jaffe et al. 2005; Foxon and Pearson 2008).

However, policies that are directed toward the development and diffusion of specific technologies are controversially discussed. It is questioned that governments should pick technology, because more efficient/effective selection institutions may exist (e.g., public-private partnerships), which also help to minimize the danger of generating a suboptimal path dependency. In the literature, it is also acknowledged that the evaluation of policy success and efficiency of dynamic policy programs in support of sustainable transitions remains an important challenge (Jaffe et al. 2005).

The failure trichotomy in knowledge exploration and exploitation: A systematic view on different causal mechanisms of innovation failures suggest to differentiate between market failures and failures that create system inertia, as well as those that inhibit emergence (Gustafsson and Autio 2011). System inertia arises due to institutional inertia or structural deficiencies in organizations influencing incumbents' activities. Emergence is inhibited due to socially and institutionally constrained sense making. It refers to the (self-)perceived roles of actors in innovation processes: "Inhibited emergence arises from cultural-cognitive frames of institutions that guide actors' assumptions concerning their own and others' roles in innovation processes and from actors' inability to bridge activities and negotiate new roles and relations" (828).

This framework helps to understand challenges of path dependence (system inertia) and path creation (inhibited emergence). It includes the insight from theorizing on technology change and sustainability transition from both the disciplinary and systemic perspectives. TM or the TIS approaches are seen as important frameworks for designing effective policies, which foster the development and diffusion of eco-technologies and help to overcome "inhibition" failures. The MLP may provide guidance on the sequential choice of long-term policy programs in support of sustainability transitions (Geels 2006). However, further research may clarify how the tension of stability in regimes (inertia) and flexibility in niches (emergence) is resolved in real-world transition contexts. In the literature, it is suggested that incrementally implemented mixes of policy instruments, institutions, networks, and organizations become promising governance solutions. This implies the need for a transition from government to governance with constantly redefined and reinvented steering mechanisms that co-evolve with a dynamic environment (Duit et al. 2010). In correspondence to these deliberations, the guiding governance principles suggested by Foxon and Pearson (2008) should be emphasized:

(i) Developing and applying the concept of 'systems failures' as a rationale for public policy intervention;
(ii) Taking advantage of the appearance of 'techno-economic' and 'policy' windows of opportunity;
(iii) Promoting a diversity of technology and institutional options to overcome 'lock-in' of unsustainable technologies and supporting institutions. (14).

In summary, theorizing on the steering of socio-technical transition has shifted to a broader systemic understanding. System failures or system barriers – both terms are often used as a more encompassing policy rationale, compared to the market failures approach, and has become the focal point of theorizing. It is complemented by a transition in the focus from government-based to governance-based steering. Theorizing on governance of sustainability transition is mainly based on structural descriptions due to a lack of causal policy frameworks. This is problematic because causal beliefs about effective governance structures underlying socio-technical transitions are one important factor to form advocacy coalitions in support of purposeful interventions (Sabatier 1998). This also limits the legitimacy and acceptance of specific governance programs and eco-technologies (Todt 2011).

There exist only a few modeling approaches that postulate and test shifts between causal steering mechanisms and their impact on system behavior characteristics. Evolutionary modeling has been suggested as a promising approach for increasing our understanding on governance structures and system behavior dynamics (Safarzynska et al. 2012). However, this line of research is quite abstract and needs to be developed further, as underlined by Faber and Frenken (2009): "Few evolutionary modeling approaches have been developed so far to describe interactions and relational structures in a system, in order to study development of a system's structure, the evolution of relations and interactions within a system, and to understand properties of emergence in relating micro-scale activities to system properties"(467).

To conclude our synopsis, we summarize our main observation with the following argument (see Box 2.3):

Box 2.3: Argument About Main Tensions in Theorizing on Sustainability Transitions

Sustainability transition research increasingly relies on process theorizing. It stresses the role of feedback mechanisms and systemic barriers as a new rationale for concerted strategy and policy making. On the other hand, it does not answer the questions of which and how causal structures influence system behavior. Therefore, the identification of effective governance structures is limited. Existing explanation frameworks do not address the following types of questions: How can emission reduction targets be met in time? How can we stay competitive during socio-technical transitions?

2.5 Toward a System Dynamics Approach for Theorizing About Socio-Technical Change

> The largest problem is not to choose among the (theoretical) alternatives but to weave them together in a way that allows each to illuminate the others (March, 1997: 10) cited by Rudolph et al. (2009: 734).

The brief literature overview gives evidence that system approaches to theory development on sustainability transitions are attractive for researchers, but also challenging. Several systemic properties are of interest and different technical terms are used to specify them. Also, we observe an emphasis on description with the elaboration of multiple categories, but few approach that focus on theoretical causation. In theorizing, this descriptive variety can lead to confusions and trigger questions like: What kind of theory is suggested? What exactly is the contribution of the theory? How do the different perspectives and approaches relate to each other? What specific technical terms indicate one-directional causalities, circular causalities, or interactions between subsystems or clusters of variables?

2.5.1 A System Dynamics Perspective

In the following, a basic system dynamics framework is presented that helps to organize the different aspects and terms that should be differentiated for an unambiguous explanation of the dynamics of socio-technical systems. This framework is based on the system dynamics school of thought on complex social systems (Richardson 1991; Sterman 2000).

Unit of analysis: The level of analysis is a socio-technical system and the units of analysis are subsystem, elements, and causalities. In the sustainability transition literature, there is a growing inter-subjective understanding that heterogeneous actor groups and networks, guiding rules (institutions), technology, resources, and infrastructures are important elements of a socio-technical system. Those can be grouped in different subsystems, depending on core activities (production, knowledge generation, use. . .). The grouping should depend on the problem framing or the focus of theorizing. For the formulation of propositions, the causal interactions between attributes or specific dimensions of the elements (e.g., level of energy efficiency of competing technologies) are of interest and not the elements themselves. Descriptive theorizing can become useful to identify the relevant attributes or dimension (e.g., innovativeness of actor groups, sustaining versus disruptive innovation, etc.).

Systemic properties: Two core systemic properties and two dimensions that are interrelated should be differentiated. The core systemic properties of interest are the structure of a socio-technical system and its behavior over time, as illustrated in Fig. 2.2. Both the system structure and the behavior may be either stable or change over time. The system structure refers to causalities between element- or subsystem-specific attributes. For example, high resources of incumbent actor networks lead to more activities than low resources of new actor networks. There may emerge qualitative change in the structure if new institutions or new actor networks are established. Circular causalities within a system are important process structures that influence system behavior over time. They help to link system structure to behavioral characteristics. Behavioral characteristics of a socio-technical system can be described by different system indicators. Their properties can be measured with time series that become the reference variable of the system behavior of interest. The work by Grübler et al. (1999a, b, 2002) is an research exemplar that provides most useful data on system behavior characteristics. Stable technology diffusion paths point to incremental innovation trajectories and stability in the evolution of the system. Contrarily, qualitative changes in the reference variables indicate radical innovations and shifts in the guiding rules.

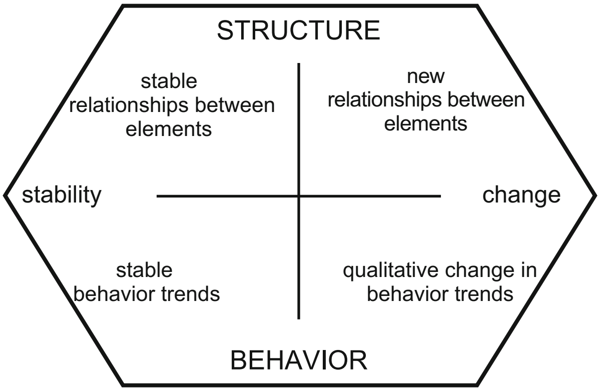

Fig. 2.2 Core properties and analysis units of a system dynamics perspective

Technical terms: In our reference literature, we have observed a plethora of technical terms that have been used to describe, analyze, and explain socio-technical transitions. We refer to terms like drivers, motors, endogenous and exogenous forces, pressure, incentives, functions, causal mechanisms, reinforcing feedback, structures, processes, alignment, and transition from one system to another. We understand that the variety in the terms can be explained by the different reference disciplines, modes of theorizing, or levels of abstraction.

We suggest developing a more standardized terminology to increase the inter-subjective clarity of their meaning. For analytical precision, we suggest distinguishing between terms that refer to the elements of a system, such as factors or variables. Variables are often used in operational models and can be specified as the dependent or independent variable in unidirectional causal relationships.

More complex relationships between factors, which are often indicated by unspecific terms such as drivers, forces, processes, and motors, should be specified concerning their causality. More precise terms are causal mechanisms or circular causalities that can be mapped as feedback loops.

Further, in order to clarify the meaning of alignment and pressure, it is necessary to specify the dimension and goal-gap constellation that are aligned or induce pressure in a system.

2.5.2 Tools for Describing Socio-Technical Governance Structures

The sustainability transition literature refers to multiple factors and processes that steer system evolution. But the question arises: How can they be explicated for a concrete action context? We illustrate that the mapping tools developed in the field of system dynamics are helpful for consistently explicating and communicating the important causal mechanism of a socio-technical system.

For illustrative reasons, we present a causal loop diagram that has been developed in a case study about transitions to energy-efficient housing (ee housing) in Switzerland (see also Chap. 6). We don't aim to comprehensively describe the developed causal loop diagram, but to illustrate how the mapping tools can be applied to visualize the relevant feedback loops.

Mapping tools: A feedback loop consists of fast-changing variables and slow-changing state variables; the latter are indicated by a box. State variables are critical to explain behavioral dynamics. They create nonlinearities, inertia, and provide systems with a memory. The circular causality hypothesis between variables is indicated by the interlinked arrows that form a loop. The loops have polarities, which means that they can be either reinforcing (positive) or balancing (negative). The loop polarity refers to the behavioral impact of a loop, producing either exponential change or goal-seeking behavior. If all relationships are rectified, then a loop is reinforcing. If there are an uneven number of converse relationships in a loop, it is balancing. For a more comprehensive description of the mapping tools, we need to refer to Sterman (2000) or Richardson (1995).

Process theorizing: In order to explicate the causal mechanism in a real-world decision context, these mapping tools can be applied for process theorizing.

In the diagram presented in Fig. 2.3, key factors and processes that have been steering the transition to ee housing in Switzerland are explicated. They postulate the dynamic hypothesis about the relevant governance structure. We see that the variables do not refer directly to the elements of a system, but to the interlinked dimensions of actors, behavioral rules, technology, designs, and resources. The diagram highlights four reinforcing and two balancing feedback loops: (R1) learning by doing by suppliers, (R2) acceptance dynamics by users, (R3) market pull by suppliers, (R4) economies of scale in the market; (B1) technology push by innovators, and (B2) limits to reduction by authorities.

The dynamical pressure for the evolution of the ee-trajectory in the housing system has been created by the gap between the average annual energy demand per housing unit and a political desired annual energy demand target. The latter has been updated over time. This sliding goal established a dynamic incentive to enhance technology development (B1). Technology improvements have created an innovative standard with lower energy demand per housing unit. This innovative standard has created competition dynamics that are indicated by the four reinforcing loops. Over time, they induced a decrease in the energy demand of the official building code. This adjustment process has been balanced by the willingness of the standard setting authority. Exogenous factors, such as marginal benefits calculations and the pressure from energy supply and climate change, have influenced their willingness.

From a system dynamics perspective on sustainability transitions, balancing and self-reinforcing mechanisms are important governance structures that explain temporal processes of societal steering. With this focus, we try to elaborate a causal understanding of alignment processes in the concrete socio-technical transition context. It is important to emphasize that the main contribution of such an analysis is not the identification of new factors or causal mechanisms. Important for useful

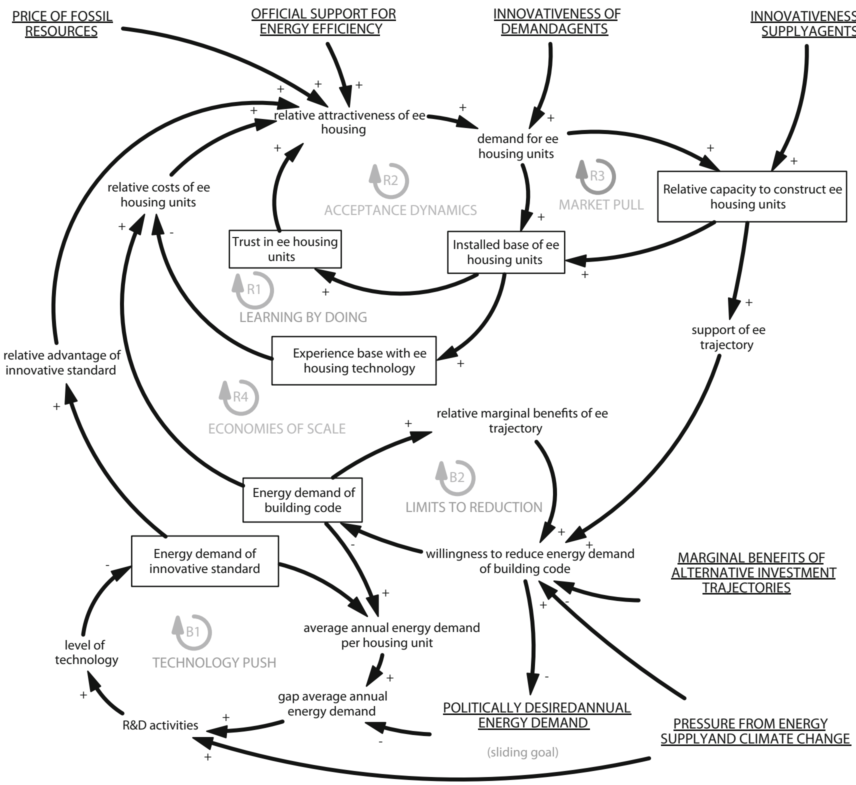

Fig. 2.3 Basic factors and processes that have played a role in the diffusion of energy-efficient housing designs in Switzerland (Adapted from Groesser and Ulli-Beer 2008)

theorizing is to identify the decisive factors and circular causalities in the concrete decision-making context, and to understand how their interactions "govern" the failure or success of transition to increased energy efficiency. However, further modeling and simulation is necessary to test the behavioral implication of the postulated governance structure, as explicated in Chap. 3.

2.6 Conclusions: Opportunities for Explanatory Models for Resolving Tensions in Sustainability Transition Studies

The aim of this chapter is to enhance the clarity of the real-world context and tensions between theoretical approaches of energy technology change and sustainability transitions. Theoretical reflection about the real-world challenge is important to develop useful decision support tools for policy and strategy making.

Understanding the real-world context is decisive to select adequate analytical perspectives.

We have started our endeavor with the assumption that tension between different theorizing approaches may exist and hamper theory integration and application.

We have elaborate answers to the three guiding research questions:

- How should distinct theorizing be understood in the context of related theorizing? The synopsis on technology change theorizing and sustainability transitions shows that extant theorizing of structural conditions and behavioral impacts of innovation on industries, economies, and the environment has only modestly inspired sustainability transition studies. Technology change research has evolved from descriptive to causality theorizing. In this, distinct conditions have been identified that explain different behavioral outcomes. Contrarily, sustainability transition studies mainly engage in the elaboration of categorization schemes and descriptive theorizing. Competitiveness deliberations are not explicitly integrated. We have also emphasized the argument that a lack of causal transition frameworks may hinder the formation of advocacy coalitions and, subsequently, acceptance of reflexive governance approaches.
- What are the sources of tensions and confusions between related theorizing? We have found evidence that the mode of theorizing, as well as the variety and application of imprecise technical terms to describe the dynamical complexity of socio-technical systems and transitions, create additional challenges of theory selection and application and enhancement. This is a specific challenge for novice innovation systems researchers, and for deducing concrete implications for strategy and policy development in concrete real-world transition contexts. We have proposed a concluding thesis about the observed tensions in theorizing on sustainability transition, highlighted in Box 2.3. It emphasizes the need for a stronger focus on causal mechanism and structure-behavior links in theorizing. This is a necessary condition to answer questions like: How can emission reduction targets be met in time? How can we stay competitive during socio-technical transitions? Therefore, we believe that there exist research opportunities for the elaboration of explanatory models, and for resolving tensions in sustainability transition studies.
- How can the tensions and ambiguities be resolved? We have suggested that a system dynamics approach for theorizing about socio-technical change helps resolve some tension in theorizing. It differentiates between two core systemic properties (system structure and behavior), that both may be stable or changing. It offers an unambiguous term frame and mapping tools for specifying multiple circular causalities of socio-technical systems that explain path dependence, lock-in, or path creation. Mapping concepts, such as feedback loop polarities, and causal loops diagrams, provide the basis for developing endogenous explanations of socio-technical transitions. These mapping tools help to weave together process theorizing from distinct perspectives for concerned decision makers in a useful way. These concepts are also a key to link system structure to behavior explanations. However, it is only by advanced simulation-based theory

building that this promise can be scientifically delivered. Only then can windows of opportunity, such as tipping points and sensitive leverage points, be identified to support socio-technical transition and the fulfillment of long-term policy objectives. How such an endeavor should be designed is addressed in Chap. 3.

References

Abernathy WJ, Clark KB (1985) Innovation – mapping the winds of creative destruction. Res Policy 14(1):3–22

Abernathy WJ, Utterback JM (1978) Patterns of innovation in industry. Technol Rev 80(7):40–47

Ackoff RL (1979) The future of operational research is past. J Oper Res Soc 30:93–104

Adner R (2002) When are technologies disruptive? A demand-based view of the emergence of competition. Strateg Manage J 23(8):667–688

Adner R (2006) Match your innovation strategy to your innovation ecosystem. Harv Bus Rev 84(4):98–107

Arrow KJ (1962) Economic welfare and the allocation of resources for invention. In: Nelson R (ed) The rate and direction of inventive activity. Princeton, Princeton University Press, pp 609–625

Arrow KJ (2000) Increasing returns: historiographic issues and path dependence. Eur J Hist Econ Th 7(2):171–180

Arthur WB (1989) Competing technologies, increasing returns, and lock-in by historical events. Econ J 99:116–131

Arthur WB (1994) Increasing returns and path dependence in the economy. The University of Michigan Press, Ann Arbor

Arthur WB (1999) Complexity and the economy. Science 284(5411):107–109

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(3):407–429

Burns TR, Flam H (1987) The shaping of social organization: social rule system theory with applications. Sage, London

Cainelli G, Mazzanti M, Zoboli R (2011) Environmental innovations, complementarity and local/global cooperation: evidence from North-east Italian industry. Int J Technol Policy Manage 11(3–4):328–368

Christensen CM (2002) The rules of innovation. Technol Rev 105(5):33–38

Christensen CM (2003) The Innovator's Solution. Harvard Business School Press, Boston

Christensen CM (2006) The ongoing process of building a theory of disruption. J Prod Innov Manage 23:39–55

Christensen CM, Rosenbloom RS (1995) Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network. Res Policy 24(2):233–257

Coenen L, Díaz López FJ (2010) Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities. J Cleaner Prod 18(12):1149–1160

Cohen W, Levinthal D (1990) Absorptive capacity: a new perspective on learningn and innovation. Adm Sci Q 35:128–152

Diehl E, Sterman JD (1995) Effects of feedback complexity on dynamic decision making. Organ Behav Hum Decis Process 62(2):198–215

Dolata U (2009) Technological innovations and sectoral change: transformative capacity, adaptability, patterns of change: an analytical framework. Res Policy 38(6):1066–1076

Dosi G (1982) Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. Res Policy 11:147–162

Duit A, Galaz V, Eckerberg K, Ebbesson J (2010) Governance, complexity, and resilience. Glob Environ Chang 20(3):363–368

Edquist C (2004) Systems of innovation: perspectives and challenges. In: Fagerberg J, Mowery D, Nelson R (eds) The Oxford handbook of innovation. Oxford University Press, Oxford, pp 181–208

Etzkowitz H, Leydesdorff L (2000) The dynamics of innovation: from National Systems and 'Mode 2' to a triple helix of university-industry-government relations. Res Policy 29(2):109–123

Faber A, Frenken K (2009) Models in evolutionary economics and environmental policy: towards an evolutionary environmental economics. Technol Forecast Soc Change 76(4):462–470

Florini A, Sovacool BK (2009) Who governs energy? The challenges facing global energy governance. Energy Policy 37(12):5239–5248

Foxon TJ (2011) A coevolutionary framework for analysing a transition to a sustainable low carbon economy. Ecol Econ 70(12):2258–2267

Foxon T, Pearson P (2008) Overcoming barriers to innovation and diffusion of cleaner technologies: some features of a sustainable innovation policy regime. J Cleaner Prod 16 (1, Supplement 1):S148–S161

Freeman C (1987) Technology policy and economic performance: lessons from Japan. Pinter, London

Freeman C (1988) Japan: a new national system of innovation? In: Dosi G, Freeman C, Nelson R, Silverberg G, Soete L (eds) Technical change and economic theory. Pinter, London, pp 330–348

Freeman C (1995) The "National System of Innovation" in historical perspective. Cambridge J Econ 19:5–24

Freeman C (1996) The greening of technology and models of innovation. Technol Forecast Soc Change 53(1):27–39

Freeman C, Perez C (1988) Structural crises of adjustment, business cycles and investment behavior. In: Dosi G, Freeman C, Nelson R, Silverberg G, Soete L (eds) Technical change and economic theory. Pinter, London/New York, pp 38–66

Furman JL, Porter ME, Stern S (2002) The determinants of national innovative capacity. Res Policy 31(6):899–933

Garcia R, Calantone R (2002) A critical look at technological innovation typology and innovativeness terminology: a literature review. J Prod Innov Manage 19(2):110–132

Geels FW (2002) Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res Policy 31:1257–1274

Geels FW (2004) From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. Res Policy 33:897–920

Geels FW (2005) The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). Technol Anal Strateg Manage 17(4):445–476

Geels FW (2006) Multi-level perspective on system innovation: Relevance for industrial transformation. In: Olshoorn X, Wieczorek AJ (eds) Understanding industrial transformation: views from different disciplines. Springer, Dordrecht, pp 163–186

Geels FW (2010) Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. Res Policy 39:495–510

Geels FW, Schot J (2007) Typology of sociotechnical transition pathways. Res Policy 36(3):399–417

Giddens A (1984) The constitution of society: outline of the theory of structuration. University of California Press, Berkley

Groesser S, Ulli-Beer S (2008) Innovation diffusion in the building construction industry: empirically-based theory generation. In: Proceedings of the 26th international conference of the system dynamics society, Athens, July 20–24

Grübler A (1998) Technology and global change. Cambridge University Press, Cambridge, UK

Grübler A, Nakicenovic N, Victor DG (1999a) Dynamics of energy technologies and global change. Energy Policy 27(5):247–280
Grübler A, Nakicenovic N, Victor DG (1999b) Modeling technological change: implications for the global environment. Ann Rev Energy Environ 24:545–569
Grübler A, Nakicenovic N, Nordhaus WD (eds) (2002) Technological change and the environment. Resources for the Future, Washington, DC
Gustafsson R, Autio E (2011) A failure trichotomy in knowledge exploration and exploitation. Res Policy 40(6):819–831
Hekkert MP, Suurs RAA, Negro SO, Kuhlmann S, Smits REHM (2007) Functions of innovation systems: a new approach for analysing technological change. Technol Forecast Soc Change 74 (4):413–432
Henderson RM, Clark KB (1990) Architectural Innovation: the reconfiguration of existing systems and the failure of established firms. Adm Sci Q 35:9–30
Hendriks CM, Grin J (2007) Contextualizing reflexive governance: the politics of Dutch transitions to sustainability. J Environ Policy Plann 9(3–4):333–350
Horbach J, Rammer C, Rennings K (2012) Determinants of eco-innovations by type of environmental impact – the role of regulatory push/pull, technology push and market pull. Ecol Econ 78:112–122
Jacobsson S, Bergek A (2004) Transforming the energy sector: the evolution of technological systems in renewable energy technology. Ind Corp Change 13(5):815–849
Jaffe AB, Newell RG, Stavins RN (2005) A tale of two market failures: technology and environmental policy. Ecol Econ 54(2–3):164–174
Jordan A (2008) The governance of sustainable development: taking stock and looking forwards. Environ Plann C Gov Policy 26:17–33
Kauffman S (1995) At home in the universe: the search for the laws of self-organization and complexity. Oxford University Press, New York
Kemp R, Schot J, Hoogman R (1998) Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. Technol Anal Strateg Manage 10 (2):175–196
Kemp R, Loorbach D, Rotmans J (2007) Transition management as a model for managing processes of co-evolution. Int J Sust Dev World Ecol 14(1):78–91
Kesidou E, Demirel P (2012) On the drivers of eco-innovations: empirical evidence from the UK. Res Policy 41(5):862–870
Kim Y, Kim W, Yang T (2012) The effect of the triple helix system and habitat on regional entrepreneurship: empirical evidence from the U.S. Res Policy 41(1):154–166
Kooiman J (2000) Societal governance: levels, modes and orders of social-political interactions. In: Pierre J (ed) Debating governance: authority, steering, and democracy. Oxford University Press, Oxford
Markard J, Truffer B (2008) Technological innovation systems and the multi-level perspective: towards an integrated framework. Res Policy 37(4):596–615
Markard J, Raven R, Truffer B (2012) Sustainability transitions: an emerging field of research and its prospects. Res Policy 41:955–967
Meadowcroft J (2007) Who is in charge here? Governance for sustainable development in a complex world*. J Environ Policy Plann 9(3–4):299–314
Moxnes E (2004) Misperceptions of basic dynamics: the case of renewable resource management. Syst Dyn Rev 20(2):139–162
Müller M, Grösser S, Ulli-Beer S (2012) How do we know who to include in collaborative research? Toward a method for the identification of experts. Eur J Oper Res 216(2)
Nelson RR, Winter SG (1977) In search of useful theory of innovation. Res Policy 6(1):36–76
Nelson RR, Winter SG (1982) An evolutionary theory of economic change. Belknap, Cambridge, MA
Pigou A (1932) The economics of welfare. Macmillan, London

Poole MS, Van de Ven AH (1989) Using paradox to build management and organization theory. Acad Manage Rev 16(4):562–578
Porter ME, Van der Linde C (1995) Toward a new conception of the environment-competitiveness relationship. J Econ Perspect 9(4):97–118
Richardson GP (1991) Feedback thought in social science and systems theory. University of Pennsylvania Press, Philadelphia
Richardson GP (1995) Loop polarity, loop dominance, and the concept of dominant polarity. Syst Dyn Rev 11(1):67–88
Rip A, Kemp R (1998) Technological change. In: Rayner S, Malone EL (eds) Human choice and climate change, vol 2. Battelle, Columbus, pp 327–399
Rosenbloom RS (1981) Technological innovation in firms and industries: an assessment of the state of the art. In: Kelly P, Kranzberg M (eds) Technological innovation a critical review of current knowledge. San Francisco Press, San Francisco, pp 215–230
Rotmans J, Kemp R, Van Asselt M (2001) More evolution than revolution: transition management in public policy. Foresight 3(1):15–31
Rudolph JJ, Morrison JB, Carroll SJ (2009) The dynamics of action-oriented problem solving: linking interpretation and choice. Acad Manage Rev 34(4):733–756
Ruttan VW (2001) An induced innovation perspective. Oxford University Press, New York
Sabatier PA (1998) The advocacy coalition framework: revisions and relevance for Europe. J Eur Public Policy 5(1):98–130
Safarzynska K, Van den Bergh JCJM (2010) Evolutionary models in economics: a survey of methods and building blocks. Evol Econ 20:329–373
Safarzynska K, Frenken K, van den Bergh JCJM (2012) Evolutionary theorizing and modeling of sustainability transitions. Res Policy 41:1011–1024
Schot J, Geels FW (2008) Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Technol Anal Strateg Manage 20(5):537–554
Smith A, Raven R (2012) What is protective space? Reconsidering niches in transitions to sustainability. Res Policy 41(6):1025–1036
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(4):435–448
Sterman JD (1989) Misperception of feedback in dynamic decision making. Organ Behav Hum Decis Process 43(3):301–335
Sterman JD (1994) Learning in and about complex systems. Sys Dyn Rev 10(2–3):291–330
Sterman JD (2000) Business dynamics. Systems thinking and modeling for a complex world. Irwin McGraw-Hill, Boston
Sterman JD (2011) Communicating climate change risks in a skeptical world. Clim Change 108:811–826
Todt O (2011) The limits of policy: public acceptance and the reform of science and technology governance. Technol Forecast Soc Change 78(6):902–909
Tushman ML, Anderson P (1986) Technological discontinuities and organizational environments. Adm Sci Q 31:439–465
Unruh GC (2000) Understanding carbon lock-in. Energy Policy 28(12):817–830
Unruh GC (2002) Escaping carbon lock-in. Energy Policy 30(4):317–325
Unruh GC, Carrillo-Hermosilla J (2006) Globalizing carbon lock-in. Energy Policy 34(10):1185–1197
Utterback JM (1971) The process of technological innovation within the firm. Acad Manage J 24(March):75–88
Utterback JM (1994/1996) Mastering the dynamics of innovation. Boston, Harvard University Business School Press
Utterback JM (1996) Mastering the dynamics of innovation. Harvard University Business School Press, Boston
Utterback JM, Suárez FF (1993) Innovation, competition and industry structure. Res Policy 22(1):1–21

Van de Ven AH (2007) Engaged scholarship: a guide for organizational and social research. Oxford University Press, Oxford

van den Hoed R (2007) Sources of radical technological innovation: the emergence of fuel cell technology in the automotive industry. J Cleaner Prod 15(11–12):1014–1021

Voss J-P, Smith A, Grin J (2009) Designing long-term policy: rethinking transition management. Policy Sci 42:275–302

Walker G, Shove E (2007) Ambivalence, sustainability and the governance of socio-technical transitions. J Environ Policy Plann 9(3–4):213–225

Weiss C, Bonvillian BW (2009) Structuring an energy technology revolution. The MIT Press, Cambridge, MA

http://www.springer.com/978-3-642-39752-3

Dynamic Governance of Energy Technology Change
Socio-technical transitions towards sustainability
Ulli-Beer, S. (Ed.)
2013, XVII, 252 p. 60 illus., 12 illus. in color., Hardcover
ISBN: 978-3-642-39752-3