Regional Studies Annual Lecture
Regional Studies Associations Conference, Newcastle / Tyne, April 19 2011

Environmental Innovation and Sustainability Transitions in Regional Studies

Bernhard Truffer* and Lars Coenen**

*Eawag (Swiss Federal Institute of Aquatic Science and Technology) and Economic Geography, University of Bern

**Circle, Lund University

Abstract

Environmental innovations and sustainability related initiatives have received increasing attention in the recent economic geography and regional studies literature. In how far sustainability concerns might also lead to fundamental transformations in technologies, industries and life styles (so-called sustainability transitions) has however found much less resonance. Sustainability transitions have been in the focus of scholars from the field of innovation studies. However, these approaches mostly disregarded spatial aspects of these transitions until recently. We therefore map out a field of future research that might be beneficially labored by both traditions. In the paper, we will introduce core concepts but also limitations of the sustainability transitions literature. After reviewing salient lines of sustainability related research in Regional Studies, we specify promising research areas at the interface between both fields. Empirical illustrations will be provided from recent work in sustainability transition studies which started to develop more elaborate concepts of space.

1. Introduction

Consequences of and responses to global environmental change have found more and more resonance in a large number of activities of governments, firms, research institutes and civil society over the past two decades. These activities are formulated for a wide variety of territorial contexts: local citizens' movements (such as Local Agenda 21 initiatives), integrative regional or urban sustainability programs, national clean-tech industry policy strategies, EU directives or even global treaties. Often these initiatives are framed as contributing to more sustainable future structures for providing and consuming products and services. The sustainability framing demands that these products, technologies and lifestyles should guarantee that key natural processes will be able to maintain their basic quality over the long run and intra- and inter-generational equity goals should be met (Kates et al 2001, Brundtland 1987). Given the considerable risks that are associated with ongoing global environmental change, incremental adaptations are seen as insufficient. Rather radical reductions of resource throughput via products, technologies and lifestyles have to be realized in order to achieve conditions of sustainability (e.g. Stern 2006, Elzen et al., 2004).

The associated actual and envisaged transformations are obviously very relevant for cities, regions, countries and ultimately global society (Martin 2001). As a consequence, regional studies scholars have shown rising interest to engage with sustainability issues (Lawhon and Murphy, 2011, Aoyama et al 2011, Soyez and Schulz 2008, Gibbs 2006, Dicken 2002, Gibbs 2002). Following an early contribution by Angel (2000) it seems however still fair to say that a pervasive approach to the interdependencies between ecological sustainability, technological development, innovation, markets, institutions and territory is still lacking. Rather, contributions have been compartmentalized along specific topical areas (Bridge, 2008). More specifically, the impact of sustainability requirements on technological transformation processes has been addressed at two levels: specific industries and longer term socio-economic paradigms. In the first group, consequences of environmental policies on emerging eco-tech sectors (such as renewable energies, e.g. see Cooke, 2010) have been analyzed or the reduction of environmental impacts of more traditional and established industry sectors (as in the case of industrial ecosystems, see Gibbs 2002). In the second group, economic geographers have started to address the implications of sustainability concerns for long term, global socio-economic development. For instance, some have revisited an earlier proposal from Freeman (1996) who argued for an upcoming Kondratieff cycle supported by a new green "techno-economic paradigm" (Hayter 2008), which might give rise to a new wave of prosperity, new industries and new geographical centers of economic development at a global scale. All these approaches provide legitimate and necessary aspects of a geographers' engagement with sustainability. The more intricate questions, however, how and under which conditions new and radically more resource efficient socio-technical configurations emerge or, alternatively, how existing socio-technical configurations support or hinder major transformations to sustainability, have received considerably less attention. One might state somewhat pointedly that the formation and transformation of socio-technical systems has been black-boxed in much of the sustainability related regional studies literature (for some exceptions see Monstadt 2009, Truffer 2008). [1]

[1] It is interesting to note at this point that also another well-established research tradition dealing with sustainability concerns namely Ecological Economics has barely addressed technology formation problems but has identified it as a major gap recently (see Castro e Silva and Teixeira, 2011).

In this paper, we argue that the challenges posed by sustainability requirements for the development of new products, technologies and life styles, necessitate a more elaborate conceptualization of the formation and transformation of socio-technical systems and its spatial dimensions. This extends an invitation to regional studies for a more intimate engagement with the dynamics of socio-technical configurations and a stronger emphasis on early formation processes. At stake is what can be broadly termed as the formulation of a "geography of sustainability transitions" (Coenen et al forthcoming).

To this avail, we propose to scrutinize the achievements of another research tradition that defines its core analytical interest in the study of technology (and industry) formation and transformation processes. Within this tradition, an academic community dealing explicitly with sustainability related innovation processes has emerged: "sustainability transitions" research. Drawing on the founding work of evolutionary economics and several strands of social constructivist accounts of technology management, the history of technology and technology assessment (for an overview, see Truffer 2008) these scholars have developed both detailed accounts of the formation of new socio-technical configurations, as well as frameworks for analyzing prevailing socio-technical structures that either support or hinder the emergence of radically new modes of production and consumption. Two conceptual frameworks are salient: the multi-level perspective on socio-technical systems (Rip and Kemp, 1998, Geels 2002) and the technological innovation systems concept (Bergek et al 2008). Sustainability concerns enter this tradition mostly by public policy demands for supporting "radical" transformations in technologies, markets and institutions towards sustainability goals (e.g. by considerably improving the efficiency of resources use). Lately, these frameworks have received increasing policy attention. For instance since 2001, the Dutch ministry for economic affairs built its national sustainability policy on the concept of "Transition Management". This initiative was inspired by academic work related to sustainability transitions (Kemp and Rotmans 2009, Loorbach 2007, Kern and Smith 2008). Other countries have adapted elements of these approaches for informing their sustainability oriented environment, technology and even regional policies such as the UK, Finland or Belgium (Voss et al 2009).

However, as we and others have argued (Coenen et al forthcoming, Lawhon and Murphy, 2011, Smith et al 2010, Marvin and Hodson, 2010) the analytical focus on the formation and transformation of socio-technical systems came at the expense of a largely naïve conceptualization of space and place. This neglect – which may have been understandable in the early gestation phases of this research field – results in major deficits regarding explanatory power and policy advice, today. In the present paper we want to explore some possible inroads into a more encompassing conceptualization of the geography of transitions by inspecting the boundary zone that opens up between sustainable transitions and regional studies research. The undertaking is much needed because otherwise socio-technical systems scholars risk inventing poor copies of the wheels, which geographers have been constructing and using for quite some time. On the other hand, regional studies scholars might profit from considering the specifics of socio-technical dynamics more explicitly and exploring resulting problems and opportunities for regions, cities and countries.

The argument is structured as follows: First basic concepts of sustainability transition studies are introduced, elaborating on the virtues but also limitations of this literature. In the search for spatially more explicit frameworks, we review the recent literature in regional studies that has explicitly engaged with sustainability issues. This leads to the specification of major complementarities between the two research fields and an outline of topical areas and research foci that may be labored from both sides and generate important synergy.

We also sketch out two exemplary research lines where a more integrated approach has recently materialized. The paper concludes by assessing how far we got on the way to formulate a more qualified "geography of transitions" and specify the need for further research.

2. The formation of socio-technical systems and the sustainability imperative

The social science informed analysis of technological formation and transformation processes has experienced a considerable boost since the early 1980s. On the one hand, the strand of evolutionary economics provided a range of seminal concepts and perspectives for a non-deterministic account of technology development, the role of limited rationality of actors and the co-evolution of technologies and organizational forms (Nelson and Winter 1982). "Innovation" has been one of the core processes of interest because it is here that the basic formation mechanisms play out and because the capability of generating new products and technologies historically became the key success factor for competitiveness of firms, regions and entire nations (Moulaert and Sekia 2007, Asheim and Gertler 2005, Mokyr 1990). Over the following three decades an interdisciplinary field of scholarship has arisen under the label "Innovation Studies" (Fagerberg and Verspagen 2009) which hosts a number of conferences, journals and educational programs. A second stream of scholarship – Technology Studies –rooted in the history of technology (Rosenberg 1994) and Science and Technology Studies argued against techno-determinism emphasizing the co-determination of social and technological characteristics of economic development. More specific conceptual frameworks were elaborated like "large technical systems" (Hughes 1987), "social shaping of technology" (MacKencie and Wajcman, 1999), "social construction of technology" (Pinch and Bijker 1987) or "actor network theory" (Callon 1998) (for a review, see Truffer 2008).

A core tenet of these approaches is that technology and institutional aspects should not be analyzed separately when trying to understand innovation (e.g. as exemplified by the much debated "linear model" of innovation, see Freeman 1996). Rather, both aspects have to be understood in their mutual determination over time. The object of analysis should therefore not be restricted to "technologies" but rather address "socio-technical systems". The formation of socio-technical systems is conceived as a process of constructing "configurations that work" (Rip and Kemp 1998) among technological artifacts and their organizational, institutional, infrastructural, use related aspects. Early formation phases have gained considerable attention, because all major components of a socio-technical configuration are still in flux (e.g. Callon 1998, Dosi 1982, Dierkes et al 1992). On the other hand side, established and mature socio-technical configurations, may exhibit strong path dependencies that go beyond lock-in effects based on increasing economies of scale (Arthur 1994), but may be generated by the initial establishment of use patterns (David 1985), standards and infrastructures or institutional structures (Granovetter and MacGuire 1998).

2.1 Sustainability transitions - a burgeoning research field

Over the past twenty years, a subset of innovation and technology scholars has started to address environmental innovation and sustainability transitions more explicitly. An early starting point in the literature was concerned with the analysis of specific environmental innovation processes (for an overview, see van den Bergh et al 2011). One of the core problems in this literature is a somewhat overenthusiastic "technological fix" approach for solving environmental problems, which risks to neglecting systemic feedbacks such as rebound

effects. More systemic approaches actively integrate public policy concerns about longer term effects of the formation of new socio-technical systems and barriers to transformation from established ones (Smith et al 2010). Two specific sub-fields are salient in the context of our argument: the technological innovation systems approach (TIS) and the multi-level perspective (MLP). Both drew on the Innovation Studies and Technology Studies in different ways and have developed specific analytical and empirical preferences so that they form different "schools" within the broader field (Coenen and Diaz Lopez, 2010).

The Technological Innovation Systems approach (Bergek et al 2008; Markard and Truffer, 2008; Hekkert et al. 2007, Carlsson and Stankiewicz 1991) builds on insights from environmental innovation research but more explicitly adopts a systemic perspective by considering the whole range of potentially relevant actors (including governments, NGO's, research institutes etc.), their interaction networks as well as different forms of institutions relevant for innovation success (Edquist 2005). It is part of the broader family of innovation systems approaches, which have become very familiar in economic geography: the national, regional and sectoral systems of innovation (Carlsson and Stankiewicz 1991, Lundvall 1992, Malerba 2002, Cooke et al. 1997, Chang and Chen 2004). Earlier work in the TIS tradition argued that besides overly simplified accounts of "market failures" for non-successful innovation, different sorts of "system failures" had to be considered as well (Klein Woolthuis et al 2005). System failures occur when components are not available in sufficient quality for the new socio-technical configuration to form. This may be due to deficiencies on the side of actors (capability and resource deficits), inappropriate networks (coordination deficits) and mismatch or even conflict with existing institutional structures (institutional deficits) (Jacobsson and Bergek 2011). More recently, structural accounts of TIS have been complemented by an analysis of core processes (so called "functions" see Bergek et al 2008, Hekkert et al 2007, Carlsson et al 2002, Edquist 2005). The TIS concept was developed with an explicit goal to inform public policy on how to better support particular technologies that promise to contribute to future sustainable sector structures (like wind energy, biofuels, biogas digestion, photovoltaic cells, or decentralized water technologies).[2] Considerable attention therefore went into the identification of barriers for the development and diffusion of specific technologies. Recent work has however questioned this narrow supply side focus and instead proposed to look at entire production and consumption systems (Tukker et al 2008; Hemmelskamp and Weber 2004) which would have to be reorganized on order to yield more sustainable sector structures (e.g. by explicitly considering rebound effects). The corresponding processes are characterized as "system innovations" compared to incremental or radical innovations which normally focus on single technologies or products.

The second stream of research analyzing socio-technical systems has become known under the label of the multi-level perspective (MLP). It also critiques the overly narrow focus on innovation success prevalent in much of the innovation system literature (Geels 2004). This framework was elaborated based on detailed historical accounts of sector and technology formation processes. The resulting "semi-coherent" constellations of technological artifacts, infrastructures, regulations, user practices are captured by the notion of the socio-technical regime (Geels 2002). Socio-technical regimes may be stable over time spans of several decades. However at times they can go through periods of rapid transformation processes (Geels and Schot 2007). These changes are either triggered by destabilizing pressures from the societal context in which the regimes are

[2] The strong orientation of innovation system concepts at informing policy makers is in line with the other innovation systems approaches. See Sharif (2006) on the early formation context of the national innovation system framework.

embedded (so-called socio-technical landscape forces) or by rivaling upcoming socio-technical configurations (so-called niches). Niches can be seen as immature variants of potential future regime structures, i.e. they still suffer from poor alignment among the different components (technologies, institutions, use practices). Niches often only exist because of specific protective conditions such as specific use segments (market niches) or deliberate attempts of specific actors to promote new technologies (technological niches) (see Hoogma et al 2002). Successful niche development thus depends on the availability of a nurturing environment, which allows for socio-technical configuration processes to play out. Sustainability transitions, finally, are conceptualized as a shift from a historically predominant socio-technical regime to a new regime through processes acting out at the different levels of landscape, regimes and niches (hence the term Multi-Level Perspective).

The relationship between the two dominant approaches in sustainability transitions TIS and MLP is still a matter of debate. Partly this has to do with different preferences in methodological style and level of analysis or with the degree to which the different approaches relate to earlier innovation studies concepts (see Smith et al 2010). In line with a similar recent critique on territorial innovation models (Moulaert and Mehmood 2010) the two traditions can be differentiated by their scope of analysis and the relative role they attribute to the "social" in the conceptualization of socio-technical systems: innovation systems approaches focus rather narrowly on innovation success of early formation phases of new technologies and industries, whereas the MLP emphasizes transformation processes in more mature socio-technical configurations dominant in a specific sectoral field. TIS approaches have a rather simple conceptualization on how new technologies contribute to broader sectoral transformation processes, mostly limited to gaining increasing market shares. The MLP takes sectoral transformation processes to the center of its analysis. On the other hand, MLP literature has been criticized for its rather unspecific treatment of agency, a poor operationalization of core constructs and correspondingly weak empirical support for core claims (Genus and Cole 2008, Markard and Truffer 2008, Smith et al 2005).[3] The TIS literature fares somewhat better in these respects as it explicitly conceptualizes strategies of different actors and has developed quite sophisticated methodological protocols to assess system structures and functions (Bergek et al 2008; Hekkert et al 2007). Some recent contributions have proposed to bridge the sometimes contrived division among the two schools and suggested to develop a more integrated conceptual framework (e.g. Markard and Truffer, 2008). However, others have questioned the possibility of such an integration project due to diverging ontological assumptions that the different schools hold (Stirling 2011, Geels 2010).

Regarding policy implications of sustainability transitions, the problem of long term orientation of policy frameworks has been addressed explicitly (Voss, et al 2009). Sustainability transitions typically span over several decades and are therefore at odds with the usual spans of attention prevalent in political processes (electoral cycles, standard government programs, hiring spans of civil servants, etc.). In order to support long-term structural shifts, policies have to interact with many transformative changes as they unfold. Long-term policy design thus needs to be flexible, adaptive and reflexive (Voss et al 2009).[4] Emphasis is put on the interaction among different segments in society (government, civil society, industry, etc.). Explorative scenarios, experimentation and learning therefore constitute important elements in specific policy programs. An early

[3] See Geels (2011) for a recent response to these criticisms

[4] The approach of long-term policy design has several kindred counterparts in the domain of environmental and technology policy. Examples are 'foresight' (e.g. Weber 2006), 'adaptive management' (Gundersohn and Holling 2002), or 'directed incrementalism' (Grin and Grunwald 2000). More extensively on this see Voss et al (2009).

example of a reflexive policy framework that built on earlier work of Constructive Technology Assessment (Schot 1992) has become known as Strategic Niche Management (Hoogma et al 2002; Schot and Geels 2007). This approach promotes the reflexive management of real world experiments (mostly in the form of pilot and demonstration projects) in which new socio-technical configurations are developed and conditions for their up-scaling can be elaborated. Other contributions have worked out scenario methodologies based on foresight to identify potential development trajectories for entire countries (Elzen et al 2004), sectors (Truffer et al 2008), technological fields (Markard et al 2009, Raven et al 2009) or firm level strategic planning processes (Stoermer et al 2009, Truffer et al 2010). A more encompassing policy framework has later been developed in the Netherlands under the label of Transition Management (Kemp and Rotmans 2009, Voss et al 2009; Kern and Smith 2008). Since 2001, the Dutch ministry of economic affairs has been committed to a long term sustainability initiative under the label of Transition Management. It encompasses the elaboration of long term transformation goals and associated policy mixes in sectors like energy, transport, food, health or housing (Loorbach 2007). Transition management comprises five main procedural elements: (1) Establishing a transition arena (i.e. a broad constituency of representatives from industry, politics, and society that accompany the ongoing planning and implementation process), (2) developing a vision of a future sustainable sector structure, (3) identifying pathways towards these future states by means of back-casting methods, (4) setting up experiments for particularly interesting development options and (5) monitoring, evaluation and revisions (Loorbach 2007).

2.2 The missing geographical dimension

The field of socio-technical systems research oriented at future sustainable technologies (or societal transitions) has experienced a strong growth over the past two decades (Markard et al forthcoming). The field has shown definite signs of institutionalization by establishing a regular international conference, several special issues in major journals (Markard et al forthcoming, Coenen and Truffer 2011; Smith et al 2010, Berkhout et al 2009, Voss et al 2009, Geels et al 2008) and the launch of a new journal on Environmental Innovation and Societal transitions (van den Bergh et al, 2011).Despite the increasing amount of conceptual work, empirical evidence and real world applications that this field engendered, it is also fair to say that it is still nascent and partially immature. A couple of recent publications have pointed to conceptual weaknesses, methodological challenges and immaturities in the design of policy advice (Coenen and Diaz Lopez 2010, Smith et al 2010, Genus and Coles 2008, Markard and Truffer 2008, Shove and Walker 2007) that represent major challenges for the field for the years to come.

One of the very salient weaknesses is related to the treatment of space in socio-technical systems studies (Coenen et al forthcoming, Hodson and Marvin 2010, Smith et al 2010, Truffer 2008, Cooke 2010). Recently, scholars in Urban Studies for instance have explicitly explored the role of cities in low carbon transitions (Bulkeley et al 2010) and detailed some of the many different ways of thinking about the roles of cities in the context of sustainability transitions - the city as a transition actor, as a contributor to national level transitions, through the lens of decision-making calculus, as constituted through multi-level governance coalitions of interest, the organisational cultures of urban transition, but also through ‘alternative’ spaces within the city through which often marginalized voices seek to participate in low carbon transitions.

Coenen et al (forthcoming) develop a thorough critique of both the TIS and MLP literature regarding the conceptualizations and methodological approach to spatial characteristics of the socio-technical formation and transformation processes developed in this literature. Space is only indirectly and implicitly addressed. Both socio-technical regimes and technological innovation systems are implicitly understood as globally available socio-technical structures that influence the activities of different actors largely irrespective of their actual geographical location. As an indicator of this treatment, the TIS literature talks about the "global opportunity set" on which TIS activities capitalize (Carlsson 2006) and the MLP literature talks about "global" and "local" processes although in a highly abstract and spatially decontextualized sense (Geels and Deuten 2006). In the actual empirical work however, space comes in rather heavy handed in that most of the analyses focus on formation and transformation processes in specific countries, cities or regions but without explicitly problematizing this choice. Even more problematic it gets when sustainability transitions research undertakes comparative studies of formation processes in different countries (Raven and Geels 2010, Hillman et al 2008, Negro and Hekkert 2008) where the different spatial contexts are largely treated as empty containers in which the specific formation processes play out. Building on this critique Coenen et al (forthcoming) propose two building blocks that would need further scrutiny and explicit conceptualization: institutional embeddedness and scale. We will elaborate on these dimensions in section 4 after having scrutinized potential contributions in the regional studies literature to a geography of transitions.

3. Sustainability related research in the field of regional studies

Before we review sustainability related contributions that have emerged from the field of regional studies, we first have a brief look at economic geography as this can be regarded as an important source for theory on the relationship between technology, territory and institutions (Storper, 1997), for example through various territorial innovation models (Moulaert and Sekia, 2003). Albeit a natural point of departure to study the formation and transformation of socio-technical systems, this literature seems to be most interested in analyzing locational dynamics of sectors where considerable maturation processes have already taken place and become relatively established. Apparently formation processes are of limited interest to a geographical analysis. To quote Boschma and Frenken (2006, p. 290) "place-specific features do not determine the location of new sectors because the selection pressures of existing spatial structures is still rather weak when new industries emerge. That is, the environment is considered to be of minor importance at the initial stage of development of a sector, because a gap is likely to exist between the requirements of the new firms (in terms of knowledge, skills, etc) and its environment". Notwithstanding Storper's early observation that "the geography of variety creation is highly variegated" (Storper, 1997, p. 291), formative phases and processes in new technology and industry emergence remain underemphasized (Truffer, 2008).

When it comes to the relationship between environmental innovation and economic geography, the sub-discipline has been, until very recently, largely silent. This is hardly surprising given the general neglect by economic geographers to study the relation of economic systems to the natural environment. To quote Angel (2000, p. 613): "The failure of economic geography to engage with the natural environment in anything more than limited terms is hardly a historical accident. It broadly follows the discursive construction of the natural environment within the capitalist accumulation process itself, namely, as a resource factor input to production

to be managed through market process, innovation, and technology change." Still, calls for a more active engagement with the natural environment have started to resonate throughout the sub-discipline.

Aoyama et al (2011) see for instance in their exploration of promising future research themes for economic geography the formation of new "socionatures" an important object of analysis, as it will provide fundamentally different preconditions on which future production and consumption processes have to build. A few years earlier, environmental economic geography has started to emerge as a subfield. Questions of governance moved center-stage on this research agenda, much in line with traditional human geography (Soyez and Schulz, 2008). As such, it specifically focuses on the relations among actors at multiple scales, e.g. by analyzing the way greening processes of industries are shaped by regulation on the national and international level. This particular interest for governance also creates a 'natural' interest for the Ecological Modernization literature (Braun et al., 2003) which will be discussed below. While original in its focus, environmental economic geography remains a 'topical contrivance' (Bridge, 2008). There is no joint 'epistemic project' but rather it unites the application of theories and methods of economic geography to environmental issues. As a result the field is compartmentalized in different topical islands, which flies in the face of more pervasive and integrative approach. As we shall see below, the lack of a pervasive framework to study the transformative processes underpinning socio-technical change towards sustainable systems of production and consumption, particularly in its formative phase, also characterize related literature in regional studies.

Our review takes its departure in a search on the papers which have been published in the Journal Regional Studies since 1993 and which referred explicitly in abstract or title to sustainability concerns. We found 47 papers. One strand of literature is primarily geared to assessing and quantitatively measuring the state of sustainable development in regions (Munday and Roberts, 2006; Turner, 2006; Nijkamp et al, 2004). These studies largely comprise statistical analyses of conventional economic indicators, ecological food prints, happiness studies and so on and ask about the impact of these criteria on distributional issues, for instance. Other contributions have highlighted the interdependence of sustainable regional development with natural resources and eco-systems, for example in the context of tourism (Fernandex, 2007) and agriculture (McManus, 2008). In addition there are a number of studies reporting on sectoral transformations in specific sectors, such as food (Morgan, 2008; Donald, 2008) waste management (Phillips et al., 2000) and forestry (Marcouillet et al., 1996).

Besides these empirically oriented contributions, a number of more conceptually and theoretically programmatic contributions can be identified. These contributions can be organized around the following strands, an engagement with (1) Ecological Modernization and Regulationist Approaches, (2) theory of Industrial Eco-systems and, (3) what can be considered as the most prominent thread in regional studies, the development of a framework to analyze policy processes that help shape 'sustainable regions'.

In response to Angel's (2000) appeal for more pervasive approaches to bring environmental concern and performance into the (spatial) analysis of economic activity, Gibbs (2006) proposes ecological modernization, strengthened with insights from regulationist work, as a resourceful literature. In contrast to more radical 'green' approaches such as deep ecology, ecological modernization claims to provide a constructive approach to adapt capitalist societies to fit within the earth's ecological carrying capacity drawing primarily on scientific knowledge, technical progress, economic growth and democratic decision-making (Huber, 2008; Jänicke, 2008;

Hajer, 1995; Mol and Sonnenfeld, 2000). Moreover, according to Gibbs (2000), ecological modernization offers a more rigorous perspective compared to the allegedly vague and all-encompassing notion of sustainable development. Key to the envisioned ecological modernization process is the institutionalization of ecological aims in the restructuring of production and consumption. While the original ecological modernization literature lacks an explicit spatial focus, it places territorial emphasis on the role of the nation state and the institutional reform that has taken place in so-called pioneering countries (Japan, the Netherlands, Germany, Sweden and Denmark) in decoupling material flows from economic flows through environmental policy making. Following Porter and van der Linde (1995), stringent environmental regulation is thus seen as the most important pre-condition for eco-innovation to allow for increased environmental performance to take place in tandem with global competitiveness through the development of lead markets (Huber, 2008). Yet, despite its focus on the institutional reorganization of society, the approach offers little detailed analysis of the forms of institutional change that are required and the power relations implied in this process (Gibbs, 2006). This critique is particularly pregnant in light of a multi-scalar perspective which questions the territorial premium allotted to the national level (e.g. most of the pioneering countries mentioned above consist of small, open economies that depend heavily on export markets). Therefore Gibbs (2006) advocates a more pronounced appreciation of Regulation theory to spell out processes of contestation and conflict between and among various groups of actors which, in turn, gives way to variegated geographies of ecological modernization struggles. This approach is indeed helpful in specifying the geography of sustainability transitions as it acknowledges and opens up for a variety of transition pathways linked to political-economic shifts at the local, national and international scales (Krueger and Gibbs, 2008). At the same time, we maintain that this approach maintains a blind eye to the (trans-)formative potential of sustainable socio-technical systems. Whilst ecological modernization has broadened its focus over time, it has been criticized for singularly focusing on a 'technical fix' through clean technologies (York and Rosa, 2003). As a result, ecological modernization theory has only been partially able to explain why, when and where certain technological changes have (or not) occurred (Gibbs, 2006) and, thus, is subject to criticism for technological determinism. Its theoretical purchase is limited to providing a meta-narrative: it is ill-equipped to make explanatory, let alone predictive, claims about the direction, rate and constituents of technological change.

In contrast, contributions that have ventured into literature on industrial ecosystems have positioned technology at the heart of their analysis. In an industrial ecosystem effluents and wastes from one process serve as the input material for processes or are recycles for further production mimicking natural ecological systems (Dunn and Steinemann, 1998). In doing so, industrial ecology represents a win-win-win outcome as it suggests increasing business competitiveness, reducing waste and pollution, creating jobs and improving working conditions and offers a unique basis for local and regional cluster development (Deutz and Gibbs, 2008). This literature emphasizes the importance of geographical co-location and proximity advantages to create environmental and resource synergies by connecting different energy and material flows across different industries (Chertow et al., 2008). This dimension is fairly unaddressed in most discussions on the role of proximity for innovation (Coenen et al., 2010; Boschma, 2005). However, the focus on material and energy exchanges seems to come at the deficit of the social processes involved in eco-industrial development. The problem is effectively reduced to a technical engineering problem how to design an 'optimal' industrial eco-park. Moreover, there is little insights in studies of such eco-parks on the extent of impact and/or spillover to the wider local and regional economy. Analogous to earlier discussion on the role of science parks for regional

development there exists a risk that industrial eco-systems remain treated as primarily localized systems (Massey et al., 1992).

Probably the most developed comprehensive contribution on regional aspects of sustainable consumption and production can be found in the research stream that looks into policy processes that help shape 'sustainable regions' (Haughton and Morgan, 2008). It departs from the observation that even though sustainable development has gained a lot of prominence in policy discourses at the regional level, most of it has a very strong economic development connotation through issues of wealth distribution, social cohesion and equity (Haughton et al., 2008; Davidson and Lockwood, 2008; Mainwaring et al., 2006). While this can partly be read against the guise of a need to broaden the perspective (to include environmental and social dimensions of sustainability), it also restates the importance and persistence of economical dimensions of sustainability (which arguably are downplayed or demonized in parts of the sustainability transitions literature). Following up on the above arguments laid out by Gibbs (2006) green regional sustainable development is one among many rationales. By zooming in on regional responses to the sustainable development imperative, a wide variety of 'on the ground' responses is disclosed (Lafferty and Narodoslawsky, 2003; Haughton and Counsell, 2004; Hardy and Lloyd, 1994; Chatterton, 2002). While this diversity is resourceful in terms of variety creation through regional policy experimentation in what can be considered a formative stage in the development and implementation of policy for sustainable regions, there is a substantial risk of limiting the discussion to 'little victories' (Haughton and Morgan, 2008). In this we find an interesting analogy to recent policy insights in the sustainable transitions literature in what is here coined as the crucial issue of 'upscaling' or 'aggregating' sustainable niche projects towards broader and more widespread application in society or, phrased differently, to accelerate the process from the initial 'niche' to a large scale transformation that replaces dominant (unsustainable) practices (Geels et al., 2008; Raven et al., 2010). What regional studies, and in particular work on sustainable regions, has to offer in this respect concerns a detailed appreciation of the need to conceptualize these challenges in a socially and politically contested and multi-scalar perspective.

To sum up, we conclude that regional studies provide some building blocks on which a more elaborate concept of geographies of transition could build. However, it is also fair to say that a comprehensive framework is not yet in sight. The major weaknesses being that technologies and sectoral (trans-)formation processes rarely receive very explicit consideration. Either there is a strong focus on institutional change at the expense of technological change, regional production structures at the expense of consumer and citizen related processes or alternatively a strong but singular focus on (experimental) policies for regional sustainability. The complementarities between regional studies and transitions studies therefore warrant some further scrutiny.

4. Mapping out the trading zone

In order to specify a productive intellectual trading zone among regional studies and sustainability transitions research, it is appropriate to first specify the relationships between different approaches and perspectives within both fields, which exhibit much more internal heterogeneity than the general introduction might have suggested. This will then provide a basis to identify five conceptual building blocks that a "geography of

transitions"-framework would have to accommodate. Finally some illustrative research lines are presented in the third part of this section that started to cross conventional building blocks dominant in the two traditions.

4.1 The structure of selected boundary zones

The different research strands that have been introduced so far cannot be mapped into scholarly territories with neat boundary lines. Rather we have a set of partly overlapping, partly separated schools of thought, which put different emphases on specific parts of reality, have established specific methodological preferences or even hold to fundamentally different ontological assumptions. Before basic building blocks of a research agenda can be identified it is therefore appropriate to sketch out the relationships among some of the more salient approaches. We will briefly address the complementarities but also the shared blind spots of three exemplary pairs of approaches: (i) the technological innovation studies and territorial innovation models, (ii) sustainability transitions research and ecological modernization, and finally (iii) the multi-level perspective and the regulation school.

Technological innovation systems and territorial innovation models (as reviewed by Moualert and Sekia 2003) share many characteristics and ambitions: a systemic view on structures and functions in technology development, a critique of methodological individualism prevailing in neoclassical economics and a strong orientation at informing policy makers (Sharif 2006). The foundational publication on technological systems by Carlsson and Stankiewicz (1991) criticized the national systems of innovation literature of dealing too naively with space. They emphasized that new technologies often started in specific local environments and networks mostly transcended national boundaries. One reading of this debate is that the different innovation system schools agree on the importance of institutional embedding for innovation success but diverge on whether coherent institutional structures are primarily formed in specific places (nations regions, locales) or along specific technological requirements irrespective of space and scale (e.g. as in Garud and Karnoe, 2003). The later, more sustainability oriented TIS research focused more strongly on early formation phases of hopeful technologies and often abstracted from specific spatial contexts. With the development of these technologies into more mature industry sectors, this neglect seems however much more problematic. Following Moulaert and Mehmood (2010) we see a shared weakness in technological and territorial innovation system approaches in the overemphasis on explaining innovation success. This comes with a partial neglect of those formation processes where users and broader political context conditions play an important role. However, some recent TIS work has started to extend innovation systems analysis into the realm of market formation (Dewald and Truffer 2011a). Also, issues of scale have often not received sufficient attention both in territorial innovation models (Moulaert and Mehmood, 2010, Bunnel and Coe, 2001) as in TIS studies (Coenen et al forthcoming, Carlsson 2006). By following the actors and networks forming around a new technological core and not a priori assuming a geographical delimitation, multi-scalarity can be addressed more explicitly (see for instance Binz and Truffer, forthcoming b). However in order to tap this potential, TIS approaches would first have to specify how spatial institutional embedding and scale can be brought into their framework.

Sustainability transitions research shares some features with the ecological modernization literature. Both focus on the enabling role of the sustainability imperative and its expression in public policy discourses. Especially in its policy implications such as the transition management approach as developed in the Netherlands (Kemp and Rotmans 2009, Loorbach 2007) seem to lead to similar policy implications. However, in our view the

sustainability transitions research has a more explicit treatment of early formation processes and is therefore less likely to fall into a techno-deterministic trap. Furthermore, sustainability transitions research does (mostly) not assume a historical drive towards a more sustainable future but is more open to a symmetrical analysis of the actual effectiveness of different sustainability initiatives. A shared weakness of both approaches is however that the treatment of power and politics seems to be weakly developed so far (see Voss et al 2009 for transition studies or Gibbs 2006 regarding the ecological modernization literature).

Finally, the relationship between sustainability transitions research and the rich tradition of critical theory developed in economic geography promises high synergy (Lawhon and Murphy 2011). Specifically the regulationist approach seems complementary to the conceptualization of socio-technical systems as conceived in the MLP. The core concepts of the regulationist approach, the mode of production, the regime of accumulation and the mode of social regulation form the backcloth in which specific socio-technical regimes develop. The formation of "configurations that work" will be impregnated by broader relations of production and consumption prevailing in specific historical periods of capitalist societies. So far, the MLP framework conceptualizes these larger context conditions by the term of socio-technical landscape forces (Geels and Schot 2007). However, this landscape is mostly defined as a conglomerate of "outside factors" impacting the historical trajectory of a socio-technical regime, like changes in oil prices, wars, major discoveries, general societal trends, etc. The MLP does not account for broader societal interdependencies among landscape factors. A regulationist interpretation of the structure of this landscape would therefore add considerable substance to the analysis of transitions. However, socio-technical regimes should not be seen as mere sub-structures of broader societal power configurations. The degree of autonomy or malleability of a specific socio-technical regime in a specific historical period has to be determined empirically. Moss (2009) for instance shows how the core structure of the socio-technical electricity regime in the city of Berlin remained essentially unchanged during the whole sequence of fundamental societal transformation processes ranging from the pre-WWII period, through the times of the Nazi, into the GDR decades and still remained intact after the fall of the Berlin wall. One benefit of triangulating the multi-level perspective with critical theory would be that the problem could be addressed of whether technologically "radical" innovations are also socially and politically radical or whether the radical innovation narrative used by specific actors actually contributes to a further entrenchment of prevailing social and economic relationships. A somewhat less dramatic interpretation of this problem is in how far new socio-technical transition narratives and activities mainly address environmental efficiency or whether they also address issues of social justice or economic livelihood. These questions open up a potentially fruitful research field that enables sustainability transitions research to more explicitly address power issues (Meadowcroft 2011, Voss et al 2009). On the other hand it might provide a more specific conceptualization of innovation and technical change for regulationist approaches as suggested by Hayter (2008) or Gibbs (2006).

4.2 Conceptual building blocks

Based on the analysis elaborated so far, five basic conceptual building blocks can be identified, which have strong footholds in one of the two scholarly fields and promise considerable synergy. Sustainability transitions and regional studies research share the emphasis on institutional embedding as a key precondition for innovation and transformation processes to succeed. The former focuses more explicitly on institutional arrangements that develop in support of a technology in the broader technological or sectoral environment, whereas the latter emphasize the importance of varying and interdependent institutional configurations in

specific places. We don't want to suggest that both perspectives should be conflated but rather that they represent two, sometimes independent but highly complementary analytical perspectives on technological dynamics. As a third conceptual building block, we propose the detailed account of early formation processes of socio-technical configurations, which is particularly well developed in the sustainability transitions literature. As a fourth dimension, we identified the conceptualization of scale as largely underdeveloped in sustainability transitions research and a field of growing interest in the regional studies literature. Fifth and finally, power should be addressed more explicitly in order to critically analyze claims of potentially desirable (sustainable) transformations uttered and promoted by specific actors and the likely consequences of these narratives and actions on different segments of society.

The first basic building block of a geography of transitions relates to the analysis of established socio-technical configurations. The socio-technical regime concept addresses these structures explicitly. It is analytically more elaborate than the sectoral innovation system concept as it allows for the identification of different socio-technical regimes to co-exist in a specific industrial sector (e.g. an automobility regime and a public transport regime for individual mobility)(see Geels 2004). Furthermore, it does not assume any *a priori* set sectoral boundaries but defines regimes by the existence of matching patterns and internal coherences between material and social structures. More dynamically the socio-technical regime concept emphasizes historical formation processes, conditions for path dependencies and resulting socio-technical trajectories. And related to agency, these coherences provide a context for analyzing strategies of different actors to respond, deflect, accommodate to or ignore challenges that are provided by upcoming socio-technical configurations or by increasing pressures from the socio-technical landscape on the regime (Dolata 2009). It therefore enables an explicit analysis of agency–structure interaction both on technological development and institutional work (Lawrence and Suddaby, 2006, Oliver 1991).

The second building block relates to the analysis of institutional embeddedness of technological formation processes in different spatial contexts. The successful formation of socio-technical configurations often depends on preconditions that may vary from one region to another. For instance, socio-technical regimes may exhibit quite some degree of regional variation (a "varieties of socio-technical regimes", so to speak. See Späth and Rohracher 2011). Regimes may therefore show regionally differentiated transformation trajectories due to regionally varying impacts from landscape forces and differential resources to accommodate these pressures. The likelihood of a specific transition may therefore be very unevenly distributed in space. Also, emerging technological innovation systems typically depend on the interplay among different actors, networks and institutions that are available only in certain places and not in others. Combined, we may witness a high diversity of potential transition paths. Whether for a successful transition, regime transformation and innovation system formation have to be spatially collocated or whether these processes can be linked over larger distances (or even over different scalar levels, see below) cannot be decided on theoretical grounds alone. A better understanding of the space related configurations of resources on which innovation systems and socio-technical regimes depend will also be necessary in order to assess the adequacy of specific regional policies aiming at the support of transitions or in order to transfer lessons from successful strategies in certain regions to other contexts.

The third building block relates to the analysis of emerging socio-technical configurations. Whereas regime configurations can be identified by analyzing dominant institutions, actor strategies and technologies, emerging

configurations are *a fortiori* much more fluid (Callon 1998). As a consequence, the identification of development potentials, emerging trajectories, or potential dominant designs are much more speculative and therefore need different methods and approaches. The interplay between different kinds of actors, including besides firms and research institutes also intermediaries, policy makers, user groups and civil society groups (Davies and Mullin, 2010) has to be analyzed in order to understand the construction of new "configurations that work". These encompass not only classical innovation processes related to product maturity and performance enhancements but also the formation of value chains (Hayter 2008), the creation of new use patterns and user profiles as well as the build-up and adaptation of institutional structures. The strategic niche management and the technological innovation systems literature provide a rich conceptual toolbox to analyze these processes in detail. Here, key processes have been identified for instance in the recent work on innovation system functions (knowledge formation, guidance of the search etc.).

The fourth building block relates to a reflexive consideration of scale. It is probably fair to say that multi-scalar processes are still a matter of concern in the regional studies community (Sunley 2008, Bunnel and Coe 2001) and have been mostly ignored in the sustainability transitions literature (Coenen et al forthcoming, Carlsson 2006). Still both regime transformation as well as the emergence of new socio-technical configuration have to be conceptualized as potentially spanning over different scales and connecting distant places. Transition dynamics may then exhibit very intricate spatial patterns. An example in this context is the discussion about leapfrogging potentials in emerging economies (Binz and Truffer, forthcoming a) or a stronger engagement with developments in the global South (Lawhon and Murphy 2011, Berkhout et al 2009, Rock et al 2009). Here, spatial contexts in which new socio-technical systems are developed may be generating much more complex geographies than what conventional innovation diffusion models would predict. Another somewhat related perspective on the problem of scale is provided by Moulaert and Mehmood (2010). They criticize territorial innovation models of focusing almost exclusively on regional economies of scope and claim that economies of scale in production are relevant as well in order to maintain a competitive edge in a region. Economies of scale are intimately linked with the expansion of markets across different geographical scales. All this calls for a more relational conceptualization actors, networks and institutions in order to understand critical processes in the formation and transformation of industries (Coenen et al forthcoming, Aoyama et al 2011).

Fifth and finally, attention should be paid to issues of power, in particular by scrutinizing discourses of innovation, progress and sustainability from a political ecology perspective (Lawhon and Murphy 2011). The leeway of action of specific regional actors will crucially depend on their position relative to other regions or to higher level jurisdictions (countries or the European Union for instance). Besides these multi-level governance problems, a critical perspective should particularly help to scrutinize the discourse of sustainability transitions and work out its interrelations with prevailing power structures and interests (Hayter 2008). Lawhon and Murphy (2011) propose as potential contributions i) a critical view on framing of sustainability problems (e.g. as in Giglioli and Swyngedouw 2008), ii) a focus on different sources of power and their enactment in discourses and strategies of different actors and iii) a focus on the actual outcomes of specific transition processes and their impact on different segments of society (a "remapping" as proposed by Hayter 2008). A careful analysis of power is therefore crucial for differentiating initiatives that might actually lead to sustainability transitions from those that merely sanctify the status quo by recourse into pseudo-radical rhetoric.

These five conceptual building blocks can only be separated for analytical purposes, obviously. An encompassing analysis of potential or actual sustainability transitions has to integrate all five aspects and scrutinize their interrelations. Depending on the specific type of socio-technical configuration at stake, the stage of maturation of an innovation and the scope of the transformation envisaged certain aspects will be more prevalent than others. For instance, conventional transition studies have mostly focused on the first and/or third aspect, while neglecting the other three. This was defendable as long as the analyzed processes happened in specific regions and immediately lead to encompassing regime changes in the same geographical area. For more complex transformation patterns, however, this neglect will lead to poor results. Some of the more empirical regional studies research in turn emphasized the second or fifth aspect at the expense of the first, third and fourth. This strategy is defendable if the technology is mature enough or if the region has not much influence on an actual transition. However, if sustainability policies have to be taken seriously, these neglects are not defendable any more. We therefore maintain that both traditions would profit from more actively addressing the neglected building blocks. Obviously this opens up a very wide field of possible research topics on various aspects of sustainability transitions that we cannot possibly cover in this paper.

4.3 Exemplary research domains

In the following, we will sketch out two exemplary research domains in which a geography of transitions agenda could immediately bear fruit. It will be illustrated by some recent research carried out at this boundary zone. The first deals with the role of spatially bound resources for explaining innovation success and the second deals with the role of cities and regions as strategic managers of sustainability transitions.

A promising field of inquiry lies in a detailed analysis of formation processes of socio-technical configurations which depend on spatially localized and partially immobile resources. Sustainability transition studies, as we reviewed above do often refer rather superficially to spatial contexts in which specific processes are generated. In the famous comparative study about success and failure of wind industry formation in Denmark and the US (Garud and Karnoe, 2003) the authors distinguish between the successful “bricolage” approach followed in the European country and the failing “breakthrough” narrative that guided much of the US initiatives. Their argument can be read as if policy makers in both countries could have been equally free to choose either strategy. A geographically more informed analysis would have potentially highlighted that Danish farmers could draw on experiences in cooperative arrangements they had gained in other contexts like sharing farming machinery. Also the interpretation and political discourse on renewable energies developed in a radically different way in Europe after Tchernobyl and the US after Three Mile Islands. As a consequence the technology focused analysis remains partial and the policy implications risk to be too simplistic. More recent research has therefore started to explore the spatial preconditions for the formation of socio-technical configurations more explicitly. For instance, Coenen, Raven and Verbong (2009) have elaborated how different forms of proximity may support the formation processes in early niche development.

Another study building on the TIS tradition has explained differential growth rates in photovoltaic market among German federal states by the central role civil society movements (solar civic initiatives) had played as early “system builders” (Dewald and Truffer 2011b). Solar civic initiatives were founded by politically mobilized citizens but also encompassed professionals and researchers with the explicit goal to develop a market for decentralized PV panels in their local communities. The study shows that those federal states with a high share

of solar civic initiatives showed stronger market development before a pervasive promotional scheme (a national feed-in tariff for renewable energies) was introduced in 2000. But they continued to show 2-3 times higher market growth rates throughout the following decade. The construction of early local market structures profited from short distance interactions between different actors in the value chain, strong user-producer interaction, specific local cooperation cultures and experiments with novel support structures (see Späth and Rohracher 2011 for a similar analysis of biogas technology in Austria). The important conclusion of this study is that local formation processes not only provide an additional explanatory factor for diverging market success. More importantly: without these formation processes, the introduction of a national feed-in tariff would have been highly questionable (Jacobsson and Lauber 2006). A full account of the success story of German PV market formation would therefore have to account for the "politics" of market formation that took place at the same time as innovation system structures were built up on a local scale. For this more ambitious project, multi-scale interactions and issues of power would have to be brought into the picture. Other studies have started to conceptualize multi-scalar geographical substructures in technological innovation systems that identify regions in a relational way in the broader context of a global opportunity set (Binz and Truffer, forthcoming b) or recent work on value chains as proposed by Hayter (2008).

A second promising field relates to the role of cities and regions in promoting sustainability transitions by specific policies. There is already quite an elaborate literature in the transitions tradition dealing with the strategic management of technological niches (Hoogma et al 2002). The role of cities and regions may be to provide protected "spaces" in which experiments may take place, where the usual selection pressures are somewhat modulated and therefore the construction of socio-technical configurations can take place. Many of the transition town or other alternative technology movements may be classified under this group (Smith 2003, Davies and Mullin 2010, Seyfang and Smith 2007). Also greentech cluster initiatives supporting future regional competitiveness and job growth could be subsumed in this field (Cooke 2010, Störmer 2008). In a similar vein, there is an increasing number of initiatives of cities and regions to positioning themselves as a sustainability leader. Often these initiatives showcase specific technologies (Maassen 2011) or want to demonstrate integrated programs for sustainable urban living encompassing a broad range of new technologies like energy efficient housing, renewable energies and green public transport policies. An example for the former approach has been proposed by Carvalho et al (2011) who show how cities like Curritiba, Gothenburg or Hamburg managed successfully to gaining recognition as sustainability leaders in their countries and even globally. These cities provided a test-bed for the introduction of new technologies (alternative fuel buses in this case) and actively interacted with their local industrial competence base consisting of both SMEs and transnational companies. By this they were able to support specific technology paths for greener transport solutions that became also available to other cities and regions. The example shows that cities and regions can become powerful promoters of sustainability transitions. However, the preconditions have to be carefully analyzed and success shows often only after several decades of determined engagement. Sustainability policies therefore do not provide a quick track to prosperity for disadvantages regions.

Power plays an important role, as well. Sustainability initiatives should not only be analyzed as policy interventions but also as discursive acts in an ongoing struggle for resources and as a means to mediate between conflicts of interest in the respective regions. Cities with high flying programs for sustainability may often show very moderate success in their actual environmental and social record. As Hodson and Marvin (2011)

have convincingly shown, often there is a multitude of actors speaking on behalf of a cities' sustainability ambitions responding to specific expectations of specific constituencies but not addressing the transformation challenge in a sufficiently integrated way. The authors show empirically how several specifically appointed programs have emerged in the city of Manchester claiming to promote a more sustainable Manchester without much of a conceivable coordination and interaction. The authors conclude that the most likely outcome of this kind of sustainability proclamation is the perpetuation of prevailing interests and thus that the maintenance of predominant regime structures rather than any conceivable change towards a more sustainable city. Critical analyses such as Hodson and Marvin's (2011) thus focus on socio-technical regime structures, local embeddedness, scale and power in an encompassing way. An integrated analysis of the city cases enables geographers and transitions scholars to critically assess the plausibility and effectiveness of specific transitions programs and their likely outcomes.

5. Conclusions and outlook

In order to address the challenges of the sustainability imperative, a sound conceptual basis is needed from which one could judge which kind of regional policy programs, entrepreneurial strategies and citizens movements are more likely to contribute to the ultimate goals. In the present paper, we reviewed strands of socio-technical systems and regional studies literature in this respect and found that both were lacking essential parts to fulfill these aspirations. The regional studies literature is often not sensitive enough to analyze formation processes in much detail. This may lead to an ineffective focus of analysis on either too mature industry structures or an overemphasis of local and regional context conditions to assess the potential for major structural shifts. The sustainability transitions literature on the other hand has an explicit focus on the formation of socio-technical systems but entertains so far an overly naïve conceptualization of space, scale and power. Both approaches combined have some immediate currency for exchange regarding formation processes and institutional embeddedness. Other issues need perhaps further conceptual development on both sides: scale and power.

Saying this, we are eager to add that the sustainability focus promoted in the present paper mainly takes an analytical and not a normative stance. It is true that sustainability is a deeply normative and hence highly political issue. The threats resulting from an unquestioned prolongation of dominant technological development trajectories are real and will probably remain high on political agendas for the decades to come. The sustainability narrative may draw a good part of its mobilizing capacity for exploring solutions and overcoming conflicts of interest by its very nature of being an "essentially contested concept" (Conelly 2007; Jacobs 2006). This potential virtue also calls for due skepticism. However, both enthusiasm and skepticism should be informed by a sound conceptual understanding of the conditions for radical transformations in modes of production and consumption. The paper primarily outlined the preconditions for fulfilling the analytical ambition. We focused on proposing essential conceptual building blocks, however without negating the relevance of the normative issues associated with specific sustainability initiatives at large. We are therefore only halfway (at best) on a way to an encompassing epistemic project that some authors have proposed for a future environmental economic geography (Aoyama et al 2011, Bridge 2008, Hayter 2008).

In the present paper, we reviewed the respective literatures and provided some example for future research. The problem labeled by the sustainability problem is most likely here to stay for the coming decades and will not disappear from the geographers' agenda (Martin 2001). One way to view it is that sustainability actually merely represents a new version of a very old preoccupation of geographers. It relates to the analysis of the consequences of technological development on regions and cities on the one hand and the role that specific places and scales play in the actual formation of socio-technical configurations on the other. Geography has developed a rich tradition to address many different aspects of these problems: institutional embeddedness, scale and power. The approach chosen in this paper may be criticized by too narrowly focusing on those contributions from regional studies and economic geography that have actively addressed sustainability concerns. Probably a richer set of concepts, empirical evidence and policy advice would be available if the field had been reviewed more broadly. We see this as an invitation for scholars from economic geography and regional studies at large to engage in the quest for better concepts and policies. Perhaps it is time for mainstreaming sustainability into the attention of economic geographers at large and develop it into a truly mobilizing epistemic project for the discipline.

References

Angel, D. P. (2000). Environmental innovation and regulation. In: Clark, G. L., Feldman, M. P. and Gertler, M. S. (eds) Handbook of economic geography. Oxford, UK: Oxford University Press, pp. 607–624.

Aoyama et al 2011. Editorial - Emerging Themes in Economic Geography: Outcomes of the Economic Geography 2010Workshop. Economic Geography, 87(2), 111-126.

Arthur, B.W. 1994. Increasing returns and path-dependence in the economy. Ann Arbor: Michigan Press.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S. & Rickne, A. (2008) Analyzing the functional dynamics of technological innovation systems: A scheme of analysis, Research Policy, 37, pp. 407-429.

Berkhout, F. and Angel, D. and Wieczorek, A. (2009) Sustainability transitions in developing Asia: Are alternative development pathways likely? Technology Forecasting and Social Change 76(2)

Binz and Truffer, forthcoming b. International Innovation Systems in multiscalar space. Analyzing the emergent water recycling industry with social network analysis. Submitted to Geographica Helvetica.

Binz, C., Truffer, B. forthcoming a. Leapfrogging in Infrastructure. Identifying transition trajectories towards decentralized urban water management systems in China. Accepted for *Technological Forecasting and Social Change*. Accepted.

Boschma, R.A., Frenken, K.2006. Why is economic geography not an evolutionary science? Towards an evolutionary economic geography. *Journal of Economic Geography*, 6 (3), pp. 273-302.

Bridge, G. (2008). Environmental economic geography: a sympathetic critique. Geoforum 39, pp. 76–91.

Brundtland report 1987. Report of the World Commission on Environment and Development: Our Common Future. Transmitted to the General Assembly as an Annex to document A/42/427 - Development and International Co-operation: Environment. http://www.un-documents.net/wced-ocf.htm

Bulkeley, H., Castan-Broto, V., Hodson, M., and Marvin, S., (eds) (2010), Cities and Low Carbon Transitions, London: Routledge

Bunnell, T. & Coe, N. (2001) Spaces and scales of innovation, Progress in Human Geography, 25(4), pp. 569-589.

Callon M, 1998. “An essay on framing and overflowing: economic externalities revisited by sociology”, in The laws of the markets Ed. M Callon (Blackwell Publishers / The Sociological Review) p 244 - 269

Carlsson, B. & Stankiewicz, R. (1991) On the nature, function and composition of technological systems, Journal of Evolutionary Economics, 1, pp. 93-118.

Carlsson, B. Internationalization of innovation systems: A survey of the literature, Research Policy 35(1) (2006) 56-67.

Carlsson, B., 2006. Internationalization of innovation systems: A survey of the literature. Research Policy, 35 (1), 56-67.

Carlsson, B., Jacobsson, S., Holmén, M., Rickne, A., 2002. Innovation systems: analytical and methodological issues. Research Policy, 31 (2), 233-245.

Carvalho, L., Mingardo,G., van Haaren, J. 2011. Green urban transport policies and cleantech innovations. Evidence from Curitiba, Göteborg and Hamburg. European Planning Studies, forthcoming.

Castro e Silva, M., Teixeira, A.A.C A 2011. Bibliometric account of the evolution of EE in the last two decades: Is ecological economics (becoming) a post-normal science? Ecological Economics. 70(5), 849-862

Chang, Y.-C., Chen, M.-H., 2004. Comparing approaches to systems of innovation: the knowledge perspective. Technology in Society, 26 (1), 17-37.

Coenen, L. and Diaz Lopez (2010): Comparing system approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities, Journal of Cleaner Production 18, pp. 1149-1160.

Coenen, L., Benneworth,P. & Truffer, B. (forthcoming.) Towards a spatial perspective on sustainability transitions. Submitted to Research Policy. Accepted.

Coenen, L., Raven, R., Verbong, G. 2010. Local niche experimentation in energy transitions: A theoretical and empirical exploration of proximity advantages and disadvantages. *Technology in Society*, 32 (4), pp. 295-302.

Coenen, L., Truffer, B. 2011. Spaces and scales of sustainability transitions: geographical contributions to an emerging research and policy field. Editorial for a special issue in *European Planning Studies*. Forthcoming.

Connelly, S. 2007 'Mapping Sustainable Development as a Contested Concept', Local Environment, 12:3, 259 – 278

Cooke, P. (2010): Regional innovation systems: development opportunities from the ‘green turn’, Technology Analysis and Strategic Management, Volume 22, Number 7, pp 831-844.

Cooke, P., Uranga, M. & Etxebarria, G. (1997) Regional innovation systems: Institutional and organizational dimensions, Research Policy, 26, pp. 475-491.

David P, 1985, “Clio and the economics of QWERTY” American Economic Review 75 332 - 337

Davies, A. and Mullin, S. 2010. Greening the economy: interrogating sustainability innovations beyond the mainstream. Journal of Economic Geography.

Dewald and Truffer 2011b. The Local Sources of Market Formation: explaining regional growth differentials in German photovoltaic markets. European Planning Studies, forthcoming.

Dewald, U. & Truffer, B. 2011a. Market Formation in Technological Innovation Systems - Diffusion of Photovoltaic Applications in Germany, Industry & Innovation, in print.

Dierkes M, Hoffmann U, Marz L, 1992 Leitbild und Technik. Zur Entstehung und Steuerung technischer Innovationen (Guiding visions and technology. The formation and regulation of technological innovations) (Edition Sigma, Berlin)

Dolata, U. (2009) Technological innovations and sectoral change. Transformative capacity, adaptability, patterns of change: An analytical framework. Research Policy, 38 (6), 1066-1076

Dosi G, 1982, “Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technological change” Research Policy 11 147 - 162

Edquist, C. (2005) Systems of innovations. Perspectives and challenges, in: J. Fagerberg, D.C. Mowery & R.R. Nelson (Eds.) Oxford Handbook of Innovation, pp. 181-208 (Oxford: Oxford University Press).

Elzen, B., Geels, F.W., Green, K., 2004. System Innovation and the Transition to Sustainability: Theory, Evidence and Policy, Edgar Elgar, Cheltenham.

Fagerberg, J., Verspagen, B., 2009. Innovation studies--The emerging structure of a new scientific field. Research Policy, 38 (2), 218-233.

Freeman, C. (1996). The greening of technology and models of innovation. Technological Forecasting and Social Change 53, pp. 27–39.

Garud, R., Karnøe, P.2003. Bricolage versus breakthrough: Distributed and embedded agency in technology entrepreneurship. *Research Policy*, 32 (2 SPEC.), pp. 277-300 Geels (2011)

Geels, F. & Deuten, J. J. (2006) "Aggregation activities Local and global dynamics in technological development: a socio-cognitive perspective on knowledge flows and lessons from reinforced concrete", Science and Public Policy, 33 (4) pp. 265–275.

Geels, F. (2004) From sectoral systems of innovation to socio-technical systems. Insights about dynamics and change from sociology and institutional theory, Research Policy, 33, pp. 897-920.

Geels, F., Hekkert, M. and Jacobsson, S. (2008) "The dynamics of sustainable innovation journeys" Technology Analysis and Strategic Management 20(5) 521-536

Geels, F.W. (2010). Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective. Research Policy, 39, 495-510.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, 31, 1257-1274.

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Research Policy, 36 (3), 399-417.

Genus A., Coles, 2008. Rethinking the multi-level perspective of technological transitions. Research Policy, 37, 1436-1445.

Gibbs, D. (2000). Ecological modernization, regional economic development and regional development agencies. Geoforum 31, pp. 9–19.

Gibbs, D. (2002). Local economic development and the environment. London: Routledge.

Gibbs, D. (2006). Prospects for an environmental economic geography: linking ecological modernization and regulationist approaches. Economic Geography 82, pp. 193–215.

Giglioli, I., Swyngedouw, E. 2008. Let's Drink to the Great Thirst! Water and the Politics of Fractured Techno-natures in Sicily. *International Journal of Urban and Regional Research*, 32 (2), pp. 392-414.

Granovetter M, McGuire P, 1998, "The making of an industry: electricity in the United States", in The laws of the markets, Ed. M Callon (Blackwell Publishers / The Sociological Review) pp 147 - 173

Grin J, Grunwald A (Eds), 2000 Vision assessment: Shaping technology in 21st Century Society. Towards a Repertoire for Technology Assessment (Springer, Berlin, Heidelberg, New York)

Gunderson L.H. and Holling, C.S. 2002: Panarchy: Understanding transformations in human and natural systems. Island Press, Washington, DC .

Hajer, M. (1995). The politics of environmental discourse: ecological modernisation and the policy process. Oxford, UK: Clarendon Press.

Hayter, R. 2008. Environmental Economic Geography. Geography compass, 2/3, 831-850.

Hekkert, M., Suurs, R., Negro, S., Kuhlmann, S. & Smiths, R. (2007) Functions of innovation systems: A new approach for analysing technological change, Technological Forecasting & Social Change, 74, 413-432.

Hillman, K., Suurs, R., Hekkert, M. and Sanden, B (2008) 'Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden' Technology Analysis and Strategic Management 20(5) 592-612

Hodson and Marvin 2011. Mediating Low-Carbon Urban Transitions? Forms of Organisation, Knowledge and Action. European Planning Studies, frothcoming.

Hodson, M and Marvin, S. 2010: Can cities shape sociotechnical transitions and how would we know if they were? Research Policy 39, 477-485.

Hoogma, R., Kemp, R., Schot, J. and Truffer, B. (2002) Experimenting for Sustainable Transport. The approach of Strategic Niche Management (London: Spon Press).

Huber, J., 2008, "Pioneer countries and the global diffusion of environmental innovations: theses from the viewpoint of ecological modernization theory" Global Environmental Change 18 360-367

Hughes, T.P., 1987. The Evolution of Large Technological Systems, in: Bijker, W., Hughes, T.P. and Pinch, T. (Eds.), The Social Construction of Technological Systems. Cambridge/MA, pp. 51-82.

Jacobs, M., "Sustainable Development as a Contested Concept", pp.21-45 in Dobson, A., Fairness and Futurity: Essays on Environmental Sustainability and Social Justice, Oxford University Press, (Oxford), 2006.

Jacobsson, S. & Lauber, V. (2006) The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology, Energy Policy, 34(3), pp. 256-276.

Jacobsson, S. and Bergek, A. 2011. Innovation system analyses and sustainability transitions – contributions and some suggestions for further research. *Environmental Innovation and Societal Transitions*, 1(1) forthcoming.

Jänicke, M. (2008) "Ecological modernisation: new perspectives" Journal of Cleaner Production 16(5) 557-565

Kates, R.W., Clark, W.C., Corell, R., Hall, J.M., Jaeger, C.C., Lowe, I., McCarthy, J.J., Schellnhuber, H.J., Bolin, B., Dickson, N.M., Faucheux, S., Gallopin, G.C., Grübler, A., Huntley, B., Jäger, J., Jodha, N.S., Kasperson, R.E., Mabogunje, A., Matson, P., Mooney, H., Moore III, B., O'Riordan, T., Svedin, U. 2001. Environment and development: Sustainability science. *Science*, 292 (5517), pp. 641-642.

Kemp, R., & Rotmans, J. (2009). Transitioning policy: Co-production of a new strategic framework for energy innovation policy in the Netherlands. Policy Sciences, 42(4), 303–322.

Kern, F., & Smith, A. (2008). Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. Energy Policy, 36, 4093–4103.

Klein Woolthuis, R., Lankhuizen, M. and Gilsing, V. (2005): A system failure framework for innovation policy design, Technovation 25, 609-619

Lawhon, M and Murphy, JT (2011) Socio-technical regimes and sustainability transitions: Insights from political ecology. Working Paper, Clark University Graduate School of Geography.

Lawrence T.B. and Suddaby, r. 2006. Institutions and institutional work. In S.Clegg, C. Hardy, T.B. Lawrence, W.R. Nord (eds.) The Sage handbook of organization studies, 2. Ed. 215-154. Sage.

Loorbach, D. 2007: Transition management. New mode of governance for sustainable development. Utrecht, The Netherlands: International Books.

Lundvall, B.-Å. (1992) National systems of innovation: Towards a theory of innovation and interactive learning (London: Pinter).

Maassen, A. 2011. Heterogeneity of lock-in and the role of strategic technological interventions in urban infrastructural transformations. Europen Planning Studies, forthcoming.

MacKenzie D, Wajcman J (Eds), 1999 The social shaping of technology, (Second Edition, Open University Press, Buckingham)

Malerba, F. (2002) Sectoral systems of innovation and production, Research Policy, 31, pp. 247-264.

Markard, J. & Truffer, B. (2008) Technological innovation systems and the multi-level perspective: Towards an integrated framework, Research Policy, 37, pp. 596-615.

Markard, J., Stadelmann, M., Truffer, B. 2009. Prospective analysis of technological innovation systems: Identifying technological and organizational development options for biogas in Switzerland, Research Policy 38(2009) 655-667.

Markard, J., Raven, R., Truffer, B. forthcoming. Towards a research agenda on Sustainability Transitions. Introduction paper for the special section in *Research Policy*. Forthcoming.

Martin, R. (2001). Geography and public policy: the case of the missing agenda. Progress in Human Geography 25, pp. 189–210.

Meadowcroft, J. 2011. Engaging with the politics of sustainability transitions. *Environmental Innovation and Societal Transitions*, 1(1), forthcoming.

Mokyr, J. 1990. The lever of riches. Technological creativity and economic progress. New York: Oxford University Press.

Mol. A. And D. Sonnenfeld (eds.) (2000) Ecological Modernisation Around the World: Persectives and Critical Debates. London: Frank Cass

Monstadt, J. 2009: Conceptualizing the political ecology of urban infrastructures: insights from technology and urban studies. Environment and Planning A 41, 1924-1942.

Moss, T. 2009. Models of socio-technical change and the politics of urban infrastructure: Managing energy in Berlin between dictatorship and democracy. paper presented to the workshop "Urban Transitions/Technological Transitions: Cities and Low Carbon Transitions", Manchester, 7-8 May 2009

Moulaert, F. and Mehmood, A. 2010. Analyzingregional development and policy: a structural realist approach. *Regional Studies*, 44(1), 103-118.

Moulaert, F., Sekia, F., 2003. Territorial Innovation models: A critical survey. Regional Studies, 37 (3), 289-302.

Negro, S.O. and Hekkert, M.P. 2008. Explaining the success of emerging technologies by innovation system functioning: The case of biomass digestion in Germany, Technology Analysis and Strategic Management 20(4), 465-482.

Nelson, R., and Winter, S. (1982). An evolutionary theory of economic change. Cambridge, MA: Harvard University Press.

Oliver, C., 1991. Strategic responses to institutional processes. Academy of Management Review 16 (1), 145-179.

Pinch, T. & Bijker, W. E. (1987) The social construction of facts and artifacts: Or how the sociology of science and the sociology of technology might benefit each other, in: W.E. Bijker, T. P. Hughes, & T. J. Pinch (Eds) The social construction of technological systems, pp. 17-50 (Cambridge, MA: MIT Press).

Raven, R.P.J.M., Geels, F.W. 2010. Socio-cognitive evolution in niche development: Comparative analysis of biogas development in Denmark and the Netherlands (1973-2004). *Technovation*, 30 (2), pp. 87-99.

Raven, R.P.J.M., Jolivet, E., Mourik, R.M., Feenstra, Y.C.F.J. 2009. ESTEEM: Managing societal acceptance in new energy projects. A toolbox method for project managers. *Technological Forecasting and Social Change*, 76 (7), pp. 963-977.

Rip, A., Kemp, R., 1998. Technological Change, in: Rayner, S. and Malone, E.L. (Eds.), Human choice and climate change - Resources and technology. Battelle Press, Columbus, pp. 327-399.

Rock, M., Murphy, J. T., Rasiah, R., van Seters, P., and Managi, S. 2009: A hard slog, not a leap frog: Globalization and sustainability transitions in developing Asia. Technological Forecasting and Social Change 76, 241-254.

Rosenberg N, 1994 Exploring the black box. Technology, economics, history (Cambridge University Press, Cambridge)

Schot J, 1992, "Constructive technology assessment and technology dynamics: The case of clean technologies" *Science, Technology & Human Values* 17 36 - 56

Schot, J. and Geels, F.W. 2007. Niches in evolutionary theories of technical change, *Journal of Evolutionary Economics*, 17 (5), 605—622.

Seyfang, G. and Smith, A. (2007) Grassroots Innovations for Sustainable Development: Towards a New Research and Policy Agenda, Environmental Politics, 16(4), pp. 584-603.

Sharif, N. (2006) Emergence and development of the National Innovation Systems concept . Research Policy, 35 (5), 745-766

Shove, E. and Walker, G., (2007) "CAUTION! Transitions ahead: politics, practice, and sustainable transition management" Environment and Planning A, 39(4)

Smith, A., 2003. Transforming Technological Regimes for Sustainable Development: a role for Appropriate Technology niches? Science and Public Policy, 30 (2), 127-135.

Smith, A., Stirling, A., Berkhout, F., 2005. The governance of sustainable socio-technical transitions. Research Policy, 34 (10), 1491-1510.

Smith, A., Voß, J.P. and Grin, J. 2010: Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. Research Policy 39, 435-448.

Soyez, D., and Schultz, C. (2008). Facets of an emerging environmental economic geography. Geoforum 39, pp. 17–19.

Späth and Rohracher 2011. Local demonstrations for global transitions- Dynamics across governance levels fostering socio-technical regime change towards sustainability. European Planning Studies, forthcoming.

Stern, N. (2006): The economics of climate change – the Stern review, Cambridge University Press, Cambridge.

Stirling, A. 2011. Pluralising Progress: from integrative transitions to transformative diversity. *Environmental Innovation and Societal Transitions*, 1(1), forthcoming.

Störmer, E. 2008. Greening as strategic development in industrial change - Why companies participate in eco-networks. *Geoforum*, 39 (1), pp. 32-47.

Störmer, E., Truffer, B., Dominguez, D., Gujer, W., Herlyn, A., Hiessl, H., Kastenholz, Klinke, A., H., Markard, J., Maurer, M., Ruef, A., 2009. The Exploratory Analysis of Trade-Offs in Strategic Planning. Lessons from Regional Infrastructure Foresight. Technological Forecasting and Social Change. 76, 1150-1162.

Storper, M. (1997). The regional world. New York: Guilford Press.

Sunley, P. 2008. Relational economic geography: A partial understanding or a new paradigm? *Economic Geography*, 84 (1), pp. 1-26. .

Truffer, B. (2008) Society, technology, and region: contributions from the social study of technology to economic geography, Environment and Planning A, 40, pp. 966-985.

Truffer, B., Störmer, D., Maurer, M., Ruef, A. 2010. Local Strategic Planning Processes and Sustainability Transitions in Infrastructure Sectors. Environmental Policy and Governance. 20, 258-269.

Truffer, B., Voss, J.-P., Konrad, K., 2008. Mapping Expectations for System Transformations. Lessons for Sustainability Foresight in German Utility Sectors. *Technological Forecasting and Social Change*. 75 (2008), 1360-1372.

Tukker, A., Charter, M., Vezzoli, C., Sto, E. & Andersen M.M. (2008) System Innovation for Sustainability 1, Perspectives on radical changes to sustainable consumption and production (Sheffield: Greenleaf Publishing Ltd).

van den Bergh, J.C.J.M., Truffer, B. Kallis, G. 2011. An Introduction to Environmental Innovation and Societal Transitions. *Environmental Innovation and Societal Transitions*, 1(1), forthcoming.

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

Weber, K.M. and Hemmelskamp, J. (Eds.), 2004 Towards Environmental Innovation Systems. Springer, Heidelberg.

Weber, M. (2006). Foresight and adaptive planning as complementary elements in anticipatory policymaking: A conceptual and methodological approach. In J.-P. Voß, D. Bauknecht, & R. Kemp (Eds.) Reflexive governance for sustainable development (pp. 189–221). Edward Elgar: Cheltenham.

York, R. and Rosa, E. (2003) Key challenges to ecological modernization theory: Institutional efficacy, case study evidence, units of analysis, and the pace of eco-efficiency, Organization & Environment 16(3)