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Environmental Innovation and Sustainability Transitions in Regional Studies

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Truffer B. and Coenen L. Environmental innovation and sustainability transitions in regional studies, Regional Studies. Sustainable development and environmental innovations have received increasing attention in regional studies and the related literature. In how far sustainability concerns might also lead to fundamental transformations in technologies, industries and lifestyles (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, until recently, these approaches mostly disregarded spatial aspects. This paper therefore maps out a field of future research – the geography of sustainability transitions – that might be beneficially laboured by both traditions. The paper introduces the core concepts, but also the limitations of the transitions literature. After reviewing salient lines of sustainability-related research in regional studies, the paper specifies promising research areas at the interface between both fields. Empirical illustrations will be provided from recent work in sustainability transitions research venturing into this interface.

Sustainability  Environmental innovations  Geography of transitions

TRUFFER B. and COENEN L. Innnovation écologique et le transition à la durabilité dans les études régionales, Regional Studies. Récemment, on a prêté beaucoup plus d’attention dans les études régionales et dans la documentation connexe au développement durable et aux innovations écologiques. Cependant, il s’avère que le point jusqu’auquel la question de la durabilité pourra entraîner des transformations fondamentales de la technologie, de l’industrie et du style de vie (les soi-disant passages à la durabilité) a fait beaucoup moins d’écho. Les passsages à la durabilité sont dans les collimateurs des spécialistes des études de l’innovation. Cependant, jusqu’à récemment, ces façons n’ont pas tenu compte pour la plupart des effets spatiaux. Cet article cherche alors à esquisser un champ de recherche future – à savoir, la géographie de transitions à la durabilité – au profit des deux traditions. L’article introduit les notions centrales mais également les limites de la documentation sur les transitions. Une fois fait la critique dans régional studies du bien-fondé de la recherche, l’article précise des champs de recherche prometteurs à l’interface des deux domaines. On fournit des exemples empiriques provenant du travail récent à propos de la recherche sur les passages à la durabilité qui s’avèrent dans cette interface.

Durabilité  Innovaions écologiques  Géographie de transitions

INTRODUCTION

The consequences of and responses to global environmental change have found increasing 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 programmes, national clean-tech industry policy strategies, European Union directives or even global treaties. Often these initiatives are framed as contributing to more sustainable future structures for providing and consuming products and services. A sustainability framework demands that these products, technologies and lifestyles should guarantee that key natural processes will be able to maintain a life-supporting quality over the long run and intra- and inter-generational equity goals should be met (Kates et al., 2001; Brundtland Report, 1987). Given the considerable risks that are associated with ongoing global environmental change, incremental adaptations alone are seen as insufficient. Rather, radical improvements in resource efficiency in products, technologies and lifestyles have to be realized in order to comply with conditions of sustainability (for example, Stern, 2006; Elzen et al., 2004).

The associated envisaged and actual 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 (Lawnh on and Murphy, 2011; Aoyama et al., 2011; Soyez and Schulz, 2008; Gibbs, 2002, 2006). Following an early contribution by Angel (2000), it seems however still fair to say that a co-evolutionary 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). On the one hand, regional scholars have started to analyse the emergence of eco-tech sectors (such as renewable energies; for example, Cooke, 2010; Fornahl et al., 2011) or greening strategies in more traditional and established industry sectors (as in the case of industrial ecosystems; Gibbs, 2002). Others have revisited an earlier proposal by Freeman (1996) who suggests an upcoming Kondratieff cycle supported by a new green ‘techno-economic paradigm’ (Havter, 2008), which might give rise to a new wave of prosperity, new industries and new geographical centres of economic development at a global scale. Most recently, Aoyama et al. (2011) explored promising future research themes in economic geography. They proposed, inter alia, more engagement with the formation of new ‘socio-natures’ as these will provide fundamentally new preconditions to future production and consumption processes. All these approaches provide legitimate and necessary aspects of regional studies’ and related fields’ engagement with sustainability. However, the intricate questions, 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. It might be stated 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).

To this avail, the present authors 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 in the context of growing sustainability concerns. Within this tradition, an academic community dealing explicitly with sustainability-related innovation processes has emerged: ‘sustainability transitions’ research. Drawing on founding work in 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, more sustainable socio-technical configurations, as well as frameworks for analysing 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 on socio-technical systems (Rip and Kemp, 1998; Geels, 2002) and the technological innovation systems (TIS) 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 (for example, by considerably improving the efficiency of resources use). Lately, these frameworks have received increasing policy attention. For instance, after 2001, the Dutch Ministry for Economic Affairs built its national sustainability policy on the concept of Transition Management, a policy framework with strong roots in sustainability transitions research (Kemp and Rotmans, 2009; Loorbach, 2007; Kern and Smith, 2008). Similarly, other countries such as the United Kingdom, Finland or Belgium have adapted elements of these approaches for informing their sustainability-oriented environment, technology and even regional policies (Voss et al., 2009).

However, as the authors and others have argued (Coen et al., 2011; Lawhon and Murphy, 2011; Smith et al., 2010; Hodson and Marvin, 2010) the analytical focus on the formation and transformation of socio-technical systems came at the expense of an appropriate consideration and appreciation of space and place in sustainability transitions. This neglect – which may have been understandable in the early formation phases of this research field – results today in major deficits regarding explanatory power and policy advice. Much of the sustainability transitions literature can be criticized for being spatially blind and for (implicitly) overemphasizing the national level at the expense of other geographical levels. More specifically, the role of regions in sustainability transitions has received little attention in this literature. 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’ research agenda. The present paper will explore some possible inroads into a more encompassing conceptualization of the spatial dimensions and implication of sustainability 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 wheels, which geographers have been constructing and using for quite some time. On the other hand, regional studies scholars might profit from investigating the spatial specificities of socio-technical dynamics more explicitly and exploring resulting problems and opportunities for regions, cities and countries.

Saying this, the authors are eager to add that the sustainability focus advocated in the present paper mainly takes an analytical and not a normative stance. It is true that sustainability is a deeply normative issue. 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’ (Connelly, 2007; Jacobs, 2006). This potential virtue also calls for due scepticism. However, both enthusiasm and scepticism should be informed by a sound conceptual understanding of the conditions for radical, path-breaking transformations in systems of production and consumption. This paper primarily outlines the preconditions for analysing such core transformation processes. A thorough engagement with normative questions is beyond the scope of the present paper. For this it refers to other scholars who have provided criticism on the sustainability transitions literature (for example, Shove and Walker, 2007) or provided more constructive proposals to relate this research to the political ecology literature (Lawhon and Murphy, 2011). The authors will therefore only offer potential inroads (instead of fully fledged integrative theories) into a more encompassing epistemic project on the spatial – and particularly regional – aspects of sustainability transitions (Aoyama et al., 2011; Bridge, 2008; Hayter, 2008).

The paper is structured as follows. First, basic concepts of sustainability transition research are introduced, and the virtues and also the limitations of this literature are elaborated. In the search for spatially more explicit frameworks, the recent literature in regional studies that has explicitly engaged with sustainability concerns is reviewed. This leads to the specification of major complementarities between the two research fields and an outline of the contours of a research agenda that may be laboured from both sides to generate important synergies. In guise of an illustration, two exemplary research lines, where complementarities have recently
been explored in the literature, are also sketched out. The paper concludes by assessing how far we have gone to formulate a more qualified spatial understanding of sustainability transitions and specify the need for further research.

**THE FORMATION OF SOCIO-TECHNICAL SYSTEMS AND THE SUSTAINABILITY IMPERATIVE**

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 for a non-deterministic account of technology development, based on limitations in the rationality of actors and the co-evolution of technologies and organizational forms (Nelson and Winter, 1982). Innovation has been at the core of interest because it is here that 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, 2003; 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 programmes. A second stream of scholarship – Technology Studies – rooted in the history of technology (Rosenberg, 1994) and Science and Technology Studies argued similarly against techno-determinism emphasizing the co-determination of social, economic and technological characteristics of technology development. More specific conceptual frameworks were elaborated such as ‘large technical systems’ (Hughes, 1987), ‘social shaping of technology’ (MacKenzie 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 analysed separately when trying to understand innovation (for example, as exemplified by the much debated ‘linear model’ of innovation; Freeman, 1996). Rather, both aspects have to be understood in their co-determination over time. The object of analysis should therefore not be restricted to the hardware of ‘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) which consists of technological artefacts and their organizational, institutional, infrastructural and use-related aspects. Early formation phases have gained considerable attention, because major components of a socio-technical configuration are still in flux: technologies need to improve in performance and cost characteristics, use patterns and user preference have not yet taken definitive form, and institutions to regulate the impacts of the technology are not yet fully developed (for example, Callon, 1998; Dosi, 1982; Dierkes et al., 1992). On the other hand, established and mature socio-technical configurations may exhibit strong path dependencies beyond increasing economies of scale (Arthur, 1994), due to aligned and locked-in use patterns (David, 1985), standards, infrastructures or institutional structures (Granovetter and MacGuire, 1998).

**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 of this approach concerns a singular confidence in technological fixes for solving environmental problems, which risks neglecting dynamic feedbacks such as rebound effects. More systemic approaches actively acknowledge the multidimensional and co-evolutionary character of the formation of new socio-technical systems and barriers to transformation from established ones (Smith et al., 2010). Two specific subfields are salient in the context of the argument: the technological innovation systems (TIS) approach and the multilevel perspective (MLP).

Both drew on Innovation Studies and Technology Studies in different ways and have developed specific analytical and empirical preferences so that they form quite different schools within the broader field (Coenen and Díaz López, 2010).

The TIS systems approach (Berger et al., 2008; Markard and Truffer, 2008; Hekkert et al., 2007; Carlsson and Stankiewicz, 1991) builds on insights from environmental innovation research but adopts a systemic perspective by considering the interplay of a whole range of potentially relevant actors (including governments, non-governmental organizations (NGOs), research institutes, etc.), 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 regional studies: 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; 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 support better particular green technologies that promise to contribute to more sustainable production structures (such as wind energy, biofuels, biogas digestion, photovoltaic cells or decentralized water technologies). Considerable attention went therefore to the identification of barriers for the development and diffusion of these technologies. Recent work has however questioned this narrow technology supply-side focus and instead proposed to look at entire production and consumption systems (TUUKER et al., 2008; WEBER and HEMMELSKAMP, 2004) which would have to be reorganized in order to yield more sustainable economic structures.

A short note on the relationship between TIS and territorial innovation models (for example, as reviewed by MOULAERT and SEKIA, 2003) is appropriate here. These approaches share many characteristics and ambitions: a systemic view on structures and functions in innovation and 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 for dealing too naively with space. These authors emphasized that new technologies often started in specific local environments, while networks mostly transcended national boundaries. One reading of this debate is that the different innovation system schools agree on the importance of institutional embeddedness for innovation 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. A shared weakness in technological and territorial innovation system approaches concerns an overemphasis of science and technology as drivers of development (see also MOULAERT and MEHMOOD, 2010). This comes with a partial neglect of user-driven innovation and the pre-competitive technological formation processes where non-market users and broader political context conditions play an important role.

The second stream of research analysing socio-technical systems has become known under the label of the ‘multilevel perspective’ (MLP). It critiques the overly narrow focus on successful technologies 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 scholars identified long-lasting semi-coherent constellations of technological artefacts, infrastructures, regulations, user practices which are labelled as a socio-technical regime (GEELS, 2002). Socio-technical regimes may be stable over spans of several decades. However, at times they can undergo periods of rapid reconfiguration (GEELS and SCHOT, 2007). These changes are either triggered by destabilizing pressures from the societal context in which the regimes are embedded (so-called socio-technical landscape forces) or by rivalling upcoming socio-technical configurations (so-called niches). Niches can be seen as relatively immature variants or prototypes of potential future regime structures, that is, they still suffer from poor alignment among the different components (technologies, institutions, use practices). Niches often depend on protective conditions provided by specific use segments (market niches) or deliberate attempts of certain actors to support the new technology (technological niches) (HOOGMA et al., 2002). Successful niche development thus depends on the availability of a nurturing environment, which allows for a socio-technical configuration to mature. Sustainability transitions, finally, are conceptualized as a shift from a historically predominant socio-technical regime to a new regime through the interplay of forces attributed to the different ‘levels’ of landscape, regimes and niches (hence the term ‘multilevel perspective’ – MLP) and which exhibit strong advances regarding environmental performance, economic prosperity and societal equity.

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 (SMITH et al., 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. TIS approaches entertain a rather simple conceptualization on how new technologies contribute to broader social transformation processes, mostly limited to gaining increasing market shares and commercial deployment. The MLP, on the other hand, takes social transformation processes to the centre of its analysis. At the same time, the 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 COLES, 2008; MARKARD and TRUFFER, 2008; SMITH et al., 2005).2 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 have suggested developing a more integrated conceptual framework (for example, 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).

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 programmes, 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). 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 programmes. An early example of a reflexive policy framework, following a tradition of Constructive Technology Assessment (Schot, 1992) became 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 foresight-based scenario methods 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 (Stormer et al., 2009; Truffer et al., 2010). A more encompassing policy framework was later developed in the Netherlands under the label of Transition Management (Kemp and Rotmans, 2009; Voss et al., 2009; Kern and Smith, 2008). Transition Management comprises five main procedural elements (Loorbach, 2007):

- Establishing a transition arena (that is, a broad constituency of representatives from industry, politics, and society that accompany the ongoing planning and implementation process).
- Developing a vision of a future sustainable sector structure.
- Identifying pathways towards these future states by means of back-casting methods.
- Setting up experiments for particularly interesting development options.
- Monitoring, evaluation and revisions.

Even though Transition Management has gained some widespread recognition in policy circles (Kern and Smith, 2008), it has repeatedly been accused of adopting an overly linear and mechanistic view on the politics of transformation, power and discourse (Smith et al., 2005; Shove and Walker, 2007; see also Lawhon and Murphy, 2011).

The missing geographical dimension

The field of sustainability transitions research has experienced strong growth over the past two decades (Markard et al., 2011). The field has shown definite signs of institutionalization by establishing a regular international conference, several special issues in major journals (Markard et al., 2011; 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 breadth and depth of conceptual work, empirical evidence and real-world applications that this field engendered, it is also fair to say it is still nascent and partially immature. A couple of recent publications have pointed to conceptual weaknesses, methodological challenges and deficiencies in the conceptual foundations 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 (Hodson and Marvin, 2010; Smith et al., 2010; Truffer, 2008; Cooke, 2010). Coenen et al. (2011) developed a thorough critique of both TIS and MLP research regarding the conceptual deficits and methodological weaknesses regarding spatial characteristics of transition processes. Space is only indirectly and implicitly addressed. Both socio-technical regimes and TIS are implicitly understood as footloose cognitive and institutional structures that influence the activities of different actors largely irrespective of their geographical location. It is revealing that the TIS literature talks about the ‘global opportunity set’ on which TIS activities capitalize (Carlsson, 2006), while the MLP literature talks about ‘global’ and ‘local’ processes, although in an aspatial way (Geels and Deuten, 2006). In the actual empirical work, space enters the analysis in a rather heavy-handed way. Most of the analyses focus on formation and transformation processes in specific countries, implicitly assuming that sustainability transitions primarily unfold at the national level (Smith et al., 2010). Moreover, a number of comparative studies have been undertaken between transitions in different countries, but often these studies treat national contexts in a superficial way boiling these down to the absence of specific promotional policies (Raven and Geels, 2010; Hillman et al., 2008; Negro and Hekkert, 2008). Only very recently has this literature
started to acknowledge its lack of appreciation for systemic differences between spatial contexts (Jacobsson and Bergek, 2011; Berkhout et al., 2009). Building on this critique, Coenen et al. (2011) proposed two building blocks where transition scholars could profit from a more thorough engagement with economic geography and related fields: institutional embeddedness and scale (see also the fourth section).

SUSTAINABILITY-RELATED RESEARCH IN THE FIELD OF REGIONAL STUDIES

In the quest to elaborate a spatially more sensitive conceptualization of transition studies, the tradition of regional studies could provide important input. Therefore, the papers that have been published in the journal Regional Studies since 1993 and which referred explicitly in abstract or title to sustainability concerns were reviewed. Forty-seven papers were found. One strand in this sample 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 analyses on the spatial distribution of conventional economic indicators, ecological footprints, happiness measures, etc. Other contributions have highlighted the interdependence of sustainable regional development with natural resources and ecosystems, for example in the context of tourism (Fernández, 2007) or agriculture (McManus, 2008). In addition, there are a number of studies reporting on specific sectoral transformations in industries such as food (Morgan, 2008; Donald, 2008), waste management (Phillips et al., 2000) and forestry (Marchouillé et al., 1996).

Besides these more empirically driven 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) industrial ecosystems, and (3) what can be considered as the most prominent thread in regional studies: the development of a framework to analyse policy processes that help shape ‘sustainable regions’.

In response to Angel’s (2000) appeal to bring environmental concern and performance into the (spatial) analysis of economic activity, Gibbs (2006) proposed 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 with 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 precondition 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 salient in light of a multi-scalar perspective that questions the spatial premium allotted to the national level (for example, 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. Whilst ecological modernization has broadened its focus over time, it remains to be 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.

Contributions that have ventured into the 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 recycled 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 it offers a unique basis for local and regional cluster development (Gibbs et al.,...
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 of 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 about how to design an ‘optimal’ industrial eco-park. Moreover, there are few insights in studies of such eco-parks on the extent of their impact and/or spillover to the wider local and regional economy. Analogous to earlier discussions on the role of science parks for regional development there exists a risk that industrial ecosystems remain treated as primarily localized systems (Massey et al., 1992).

Probably the most salient 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’ (Houghton 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 (Houghton 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 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; Houghton and Counsell, 2004; Hardy and Lloyd, 1994; Chaterton, 2002). These contributions are primarily concerned with policy-led initiatives for sustainable regional development, emphasizing the role of governance experimentation and public–private coordination. Following the wider debate about regional development it acknowledges a multilevel governance perspective, including national and supra-national policy interaction. There is however little explicit attention to positioning such regional initiatives in wider transformations in systems of production and consumption and the role of socio-technical shifts underpinning these transformations.

Before this review of sustainability-related contributions that have emerged from the field of regional studies is summed up, a brief look will also be made 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 analysing locational dynamics of sectors where considerable maturation processes have already taken place and become relatively established. Mostly existing industrial development paths are investigated, whereas the origins of new paths apparently remain not much dealt with (MacKinnon et al., 2009; Foruhl et al., 2011). Nonetheless, recent work has started to take stock of the relationship between existing and new industrial development paths in regions. The recently introduced concept of related variety provides important insights with regard to questions related to the emergence of new industrial activity and economic renewal in regions (Asheim et al., 2011). In the context of regional branching processes, regions are more likely to diversify into related activities through knowledge-transfer mechanisms such as spinoff activity, firm diversification, labour mobility and social networking, there is some evidence that these knowledge-transfer mechanisms tend to have a local bias even though more empirical research is needed to strengthen this claim (Asheim et al., 2011). At the same time Boschma and Frenken (2006) warned against deterministic accounts, highlighting spatial contingency in the build up of new industry development:

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 socio-spatial 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.

(p. 290)

As such, it remains important to consider simultaneously region-specific and external factors that may trigger a window of locational opportunity for new industry to emerge in different regions. Formative and stabilizing phases and processes in new technology and industry, thus, need to be integral to this analysis. In sum, this provides a promising line of research for economic geography to study in conjunction with that of socio-technical transition research (see also Truffer, 2008), particularly in the context of sustainability concerns.

When it comes to the relationship between environmental innovation and economic geography, however, the sub-discipline has been largely silent, until very recently. This is hardly surprising given the general neglect by economic geographers to study the relationship between economic systems and the natural environment (Angel, 2000; Dicken, 2004). Still,
environmental economic geography has started to emerge as a subfield. Questions of governance moved centre 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, for example, by analysing the way greening processes of industries are shaped by regulation at the national and international levels. This particular interest for governance also creates a ‘natural’ interest for the Ecological Modernization literature, which was discussed above. 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 remains compartmentalized in different topical islands, which flies in the face of a broad and multidimensional approach.

To sum up, it can be concluded that regional studies and related field have shown an emerging interest in sustainable development and provide to some extent various building blocks to study spatial dimensions and the implications of sustainability transitions. However, it is also fair to say that a more comprehensive framework has not yet fully emerged. The major weaknesses are 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.

CONTOURS OF A GEOGRAPHY OF SUSTAINABILITY TRANSITIONS

Based on the current state of sustainability-related research in the transitions and regional studies literatures, the contours of a spatially sensitive understanding of sustainable socio-technical system formation and transformation can now be specified (Table 1). Such a conceptual framework has to adopt a multidimensional, dynamic and long-term perspective. As a consequence, it has to address early formation processes, where socio-technical configurations are still fluid and actively constructed by specific actors in particular cultural, economic and political contexts. Concomitantly it has to enable the analysis of different stabilizing forces that maintain and/or adjust socio-technical configurations under varying pressures exerted by societal, economic and environmental context factors. Taken together, such processes of formation and stabilization engender a wide variety of potential development trajectories towards future sustainable socio-technical systems. As explicated in the second section, the sustainability transitions literature proposes a number of concepts to analyse these processes, but it lacks an explicit consideration of spatial dimensions and implications. It is argued here that a stronger engagement with processes of sustainable socio-technical system formation and stabilization in regional studies not only has the potential to adjust for this spatial blindness, but also provides a platform for regional scholars to address regional sustainable development and transformation processes in a multidimensional and co-evolutionary way.

The following will specify the contours of a combined regional and sustainable transition agenda by first outlining a core meeting ground between the transitions and regional studies literature: the twofold consideration of socio-technical and socio-spatial embeddedness of transitions. However, even if successfully spelled out, this core agenda still risks suffering from considerable shortcomings. It needs additional careful consideration of at least two aspects that have found strong resonance in spatial analyses: the role of scale and power. These will be elaborated in a second subsection. Finally, two illustrative examples representing potentially seminal research lines will be introduced.

Before elaborating the argument in more detail, a note of caution is appropriate: the different perspectives alluded to above exhibit a high degree of complementarity and are likely conjointly to contribute to a more encompassing understanding of sustainability transition processes in their spatial contexts. However, this does not mean that the idea is to formulate an all-encompassing, internally coherent and fully integrated theory. Rather, the authors are aware that the inherently political characteristic of sustainability transitions necessitates the consideration of very different, and sometimes even irreconcilable, views and perspectives. The following, therefore, essentially aims at mapping out different conceptual contributions from transitions and regional studies scholars in order to specify potentially productive contact zones. This should support and enable productive academic discussion rather than prematurely close down fundamental debates.

The core of the agenda

Sustainability transitions and regional studies research share an emphasis on institutional embeddedness as a core condition for successful innovation and transformation processes. The two traditions differ, however, with regard to the specific loci where they expect to find essential institutional coherences: the former focuses on institutional arrangements that develop in support of a technology considering the broader technological or sectoral environment, whereas the latter emphasizes the interdependencies among institutional configurations in specific places. These socio-technical and -spatial institutional contexts may display a substantial degree of conjunction: the development of new product designs in combination with manufacturing structures, institutional
support structures and user profiles may happen concentrated within the confines of a specific region, yet once the socio-technical configuration has matured it is adopted more broadly by other actors across the world (for example, as in the case of early market formation in photovoltaics in Germany elaborated below). More generally, however, elements of socio-technical configurations are likely to diverge across space and, in doing so, create tensions and barriers for (either technological or regional) development. The following will specify some potential benefits of a complementary consideration of the two perspectives, differentiating roughly between emerging and mature socio-technical configurations (Table 1).

Established socio-technical configurations are relevant for sustainability transition in that they have a potential for eco-improvement of a wide number of existing products and therefore mobilize substantial relief to pressing environmental problems. At the same time, the socio-technical regime concept emphasizes technological and institutional path dependencies, which may stay in the way of more fundamental reductions of impacts (as exemplified by the thesis of carbon lock-in in the energy field; Unruh, 2000). These institutional contexts provide the background for strategies of different actors to respond, deflect or accommodate challenges that are provided by pressures from the external socio-technical landscape like those exemplified by sustainability requirements (more generally, see Dolata, 2009). It therefore enables an explicit analysis of agency-structure interaction in terms of both technological development and institutional change (Geels and Schot, 2007; Lawrence and Suddaby, 2006; Oliver, 1991). The incumbent transitions literature may however have neglected important differences across specific countries and regions in the ways such regimes play out. Socio-technical regimes may actually exhibit quite considerable geographical variation (a ‘varieties of socio-technical regimes’, so to speak; Späth and Rohracher, 2011). These may be due to variations in wider institutional context conditions and political economies, into which a specific socio-technical regime structure is embedded. This opens up leeway for actors to accommodate the basic configuration to their specific interests. Regimes may therefore be subject to regionally differentiated transformation trajectories due to varying susceptibility to ‘landscape forces’ and differential resources to accommodate these pressures. Hence, stabilizing and potentially inhibiting preconditions for sustainability transitions may be very unevenly distributed in space.

Whereas regime configurations can be observed by assessing dominant institutions, actor strategies and technologies at a specific point in time, emerging configurations are a fortiori much more fluid (Callon, 1998). As a consequence, the identification of development potentials, emerging trajectories or potential dominant designs is more speculative. The interplay between different kinds of actors, including firms, research institutes, intermediaries, policy-makers, user groups and civil society groups, in situations where no competitive products or solutions exist (Davies and Mullin, 2010) has to be analysed in order to understand the construction of new configurations that work. These encompass not only classical product and process innovations, but also innovations in value chain organization (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 TIS literature provide a rich conceptual toolbox to analyse these social

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| Socio-spatial        | Proximity advantages as key resources for formation processes  | Proximity advantages as a resource for stability and the mainten-
| embeddedness         | Green technology cluster initiatives and sustainable regions   | ance of entrenched configurations                               |
| Critical             | Regions/cities as transition ‘managers’                       | Socio-technical regimes and spatially variegated political     |
| Extensions           | Relational understanding of actors’ resource base (local nodes, global networks) | economies                                                    |
|                      | New global development patterns, for example Leapfrogging, ‘reverse diffusion’ | Stabilizing power of regime structures on a global level (for example, in structuring development trajectories of emerging economies) |
| Power                | Differential regional impacts of emerging industries          | Scalar (including regional) variations and reproduction of     |
|                      | Radicals and sustainability                                    | regime structures                                            |
|                      |                                                                | Discourse versus action in sustainability transitions          |
|                      |                                                                | Confluence of socio-technical regimes and modes of accumulation |

Table 1. Contours of a geography of transitions
construction processes in considerable detail, for instance through the analytical lens of key innovation system functions for the development and diffusion of emergent new technologies (entrepreneurial experimentation, guidance of search, market formation, etc.) or the active ‘protection’ of niches in which the new configurations can form (Smith and Raven, 2011). Socio-technical experimentation is an obvious instrument to support these formation processes. This enables institutional adaptation, constituency building, the articulation of expectations and visions, and network formation. At the same time, the alignment of emerging socio-technical configurations will be exposed to (even if moderately) selective pressures and will be actively shaped by this. In a regional context, proximity advantages (Boschma, 2005; Coenen et al., 2010) or specific local institutional configurations may play a decisive role in this. Considering this dimension will allow one to look for crucial processes that an aspatial perspective would most likely overlook or to identify the conditions of transferring lessons from successful cases from one region to another. Moreover, this approach partly resonates with aforementioned regional policy experimentation as ‘bottom-up’ initiatives to induce large-scale transformation.

In order to identify and evaluate potential sustainability transitions, the effect of formation processes of new socio-technical configurations and their interrelation with stabilization and adjustment strategies in incumbent socio-technical configurations has to be addressed simultaneously. A spatially informed, co-evolutionary transition model would insist on the recognition that new ‘green’ niches and ultimately regimes arise from an inherently asymmetric process of regional development. The development of a better theoretical understanding of factors enabling or impeding these processes requires a closer investigation into the contingencies and particularities of the spatial contexts in which sustainability transitions evolve and take place (Asheim, 2006). It requires, in other words, an understanding of transition spaces, that is, a synthesis of locally embedded contexts of events, objects and actions coupled with the wider socio-political, institutional and cultural context. This understanding recognizes why certain transformative instances of innovative and institutional interactions occur where they do and for what reason. Whereas the incumbent sustainability transitions literature has remained largely silent on these questions, it would feature as a salient topic at the intersection with regional studies acknowledging the twofold embeddedness of sustainability transitions in socio-technical and spatial configurations. Moreover, it contributes to a broader understanding of typical sustainability related topics in regional studies such as the emergence of green-tech clusters, the notion of sustainable regions, and the suggestion that cities and regions can act as transition managers as it shifts perspective from sustainable development in the region to sustainable development of the region.

Necessary extensions

The meeting ground provided by the core agenda promises considerable additional insight for both research traditions. However, it has to be acknowledged that even a combined technological and a regional perspective still risks neglecting very important problems that should be included in an analysis of the spatial dimensions and implication of sustainability transitions. Two very salient issues are the consideration of scale and power.

It is probably fair to say that the consideration of multi-scalarity is still a matter of discussion in the regional studies community (Sunley, 2008; Bunnell and Coe, 2001). One argument for engaging with scale issues has recently been provided by Mouldart and Mehmood (2010). They criticized territorial innovation models for focusing almost exclusively on regional economies of scope. They claimed that managing economies of scale in production and consumption is equally important 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. This calls for a relational conceptualization of actors, networks and institutions in order to understand critical processes in the formation and transformation of industries (see also Aoyama et al., 2011). A central topic for closer inspection concerns here the existence of complementarity and strategic coupling effects between localized assets (technology, actors and resources) and institutions, on the one hand, and activities, needs and interests of trans-local actors, on the other hand (Bat hell and Gluckler, 2003). As mentioned above, a critical examination of transition spaces would not stop at the administrative borders of territorial units (regions, nations) but would require attention for spatial dimensions and implications of sustainability transitions ‘wherever they may lead’. By eschewing scalar envelopes (Cooke, 2005) it would recognize the multilevel governance challenge to coordinate sustainability transitions encompassing local to supranational arrangements. Moreover, it acknowledges a network topology, rather than a scalar hierarchy, in terms of key actors involved in sustainability transitions.

A relational view on institutional coherences, formation processes and maintenance strategies would furthermore add a strongly needed specification of institutional embeddedness. Socio-technical regimes may be stabilized in specific spatial contexts by actors explicitly claiming that these configurations correspond to a global standard of best practice. For instance, emerging economies currently experiencing strong urban growth may be inclined to copy seemingly superior urban infrastructures in old industrialized countries. This happens despite the fact that the superiority of the corresponding socio-technical regime is increasingly questioned in industrialized countries and neglects the specific context conditions in emerging economies,
which further questions the applicability of the success model. A very telling example of such regime import concerns urban water management infrastructures based on flushing toilets in countries with considerable problems of water scarcity (Truffer et al., 2011).

Regarding the concepts of transition dynamics, it is quite remarkable that the sustainability transitions literature has so far largely ignored the problem of scale and mostly focused on innovation processes largely within the boundaries of specific countries or regions (Coenen et al., 2011; Carlsson, 2006). This seems at odds with the notion that sustainability transitions by definition imply a global dimension in order to assess development relative to a broad set of sustainability goals. The neglect of scale could be understood under the assumption of a linear view on diffusion in which new configurations are developed and tested in industrialized regions and countries before they are transferred to developing economies. The term of ‘niche aggregation’ in the MLP framework is a case in point, assuming that niches grow from a ‘local’ (here more in a socio-cognitive sense than in a geographical one) into more ‘globally’ accepted forms (Geels and Deuten, 2006). Neither has the TIS literature yet been able to address explicitly the globalization of technology development and diffusion (Carlsson, 2006). Recent empirical literature has shown that the geography of emerging technologies may exhibit highly distributed spatial patterns of development. An example in this context is the discussion about technological leapfrogging potentials in emerging economies (Binz et al., 2012; Rock et al., 2009) or new technologies, business models and life styles developing in the global South (Lawhon and Murphy, 2011; Berkhout et al., 2009). One take from this is that a spatially conscious perspective also enables one to see new phenomena and by this increase the scope of potential sustainability transition trajectories.

A relational perspective on scale has already been extensively brought to practice in much of the regional studies literature conceptualizing regional development not as development in a region but rather as development of a region. In terms of sustainable regional development, a multilevel governance perspective is widely acknowledged (Haughton and Morgan, 2008). It would however benefit this discussion also to incorporate notions of fluid and entrenched socio-technical configurations to understand better the specific governance challenges implied by regional transformation processes in light of sustainability concerns. Similarly, notions of niche and regime are potentially resourceful concepts in framing the possibilities and limitations for green-tech clusters to emerge and develop in particular regions. While the field of regional studies already takes account of the importance of global value chains for clusters (Coe et al., 2004) and ‘local node, global network topologies’ in the case of knowledge dynamics (Bathelt et al., 2004; Coenen et al., 2004) these insights may be complemented by an explicit acknowledgement of the intrinsic particularities concerning the formation and stabilization of more sustainable systems of production and consumption for emerging, green-tech industries. In a multi-scalar perspective this opens up questions regarding the spatial distribution of innovation, production and consumption in these industries and the whereabouts of agglomerations of green industrial activity.

A second line of extension relates explicitly to addressing issues of power. Sustainability transitions are by their very nature political projects. They concern future living conditions of societies on a global scale, respecting boundaries of natural systems by not impacting the development options for future generations (Kates et al., 2001). All these dimensions are intrinsically value laden. This implies that normative issues have to be addressed explicitly: the power to shape transformation processes according to the interests of specific actor groups as well as the differential impact that specific transformations might have on different segments of society. A narrow technocratic view neglecting these processes would be largely inadequate when associated with sustainability. Some have in fact argued that transitions research is overly mechanistic. Especially the approach labelled as ‘Transition Management’ has been accused of drawing a blind eye to issues of power (Smith et al., 2005; Shove and Walker, 2007). Also, TIS studies may be criticized for their sometimes overly mechanistic framing of hindering factors, market success or profitability (implicitly assuming that the market success of specific technologies would already guarantee a more sustainable society). However, it is also fair to say that transition scholars have responded to these criticisms and have started explicitly to conceptualize power into their frameworks (Meadowcroft, 2011; Avelino and Rotmans, 2009; Voss et al., 2009).

Power issues have a much longer and stronger tradition in regional studies research (Allen and Cochrane, 2007; Christopherson and Clark, 2007). Also, economic geographers who have recently started to engage with transition studies emphasize the normative political dimension by scrutinizing discourses of innovation, progress and sustainability from a political ecology perspective (Lawhon and Murphy, 2011). Critical approaches could come to bear in different realms in transition studies. Most trivially, the autonomy 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 multilevel 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 (1) a critical view on the framing of sustainability problems (for example, as...
in Giglioli and Swyngedouw, 2008); (2) a focus on different sources of power and their enactment in discourses and strategies of different actors; and (3) 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). An extensive discussion of how power may be conceptualized in transition studies is beyond the scope of the present paper, but it represents doubtless a much needed extension within a spatial analysis of sustainability transitions.

As an illustration, one example of a potentially fruitful domain of research inspired by both literatures could be the elaboration of complementarities between the regulationist approach and the concept of a socio-technical regime as conceived in the MLP. Core concepts of the regulationist approach, that is, the mode of production, the regime of accumulation and the mode of social regulation, may be interpreted as forming the backdrop 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 has conceptualized these larger context conditions with reference to socio-technical landscape forces (Geels and Schot, 2007). However, this landscape is mostly defined as a conglomerate of ‘exogenous factors’ impacting the historical trajectory of a socio-technical regime, such as 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 conceptual depth to the analysis of transitions. However, socio-technical regimes should not be seen as mere substructures 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, showed how the core structure of the socio-technical electricity regime in the city of Berlin remained essentially intact during the whole sequence of fundamental societal transformation processes ranging from the pre-Second World War period, through National Socialism (Nazism), into the decades of the German Democratic Republic (GDR) and still after the fall of the Berlin Wall. These arguments nurtured by socio-technical regime concepts might provide a more specific conceptualization of innovation and technical change within a regulationist approaches as suggested by Hayter (2008) or Gibbs (2006).

One benefit of triangulating transition studies with critical theory would be to specify 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 and interests. The transitions literature has had so far a stronger emphasis on environmental effectiveness at the expense of other societal impacts (Lawhon and Murphy, 2011). To elaborate a power-sensitive conceptualization of transitions will be especially important for the assessment of sustainability strategies formulated by specific cities and regions and therefore will also contribute to the sustainable regions literature strongly established in regional studies.

The outlined conceptual framework consisting of a core agenda and two essential extensions allows for a wide variety of approaches to analyse sustainability transitions. Depending on the specific type of socio-technical configuration under scrutiny, the stage of maturation of a technological field and the scope of the transformation envisaged, certain aspects of the core or particular extensions will be more prevalent than others. For instance, conventional transition studies have mostly focused on socio-technical embeddedness, while neglecting socio-spatial embeddedness, scale and power. This might be defendable as long as the innovation is uncontested and if the formation processes do not depend on any particular proximity advantages or locally specific institutional arrangements and immediately diffuse to the rest of global society once the formation process has been settled. Very few real-world cases will, however, fit with these heroic assumptions and, therefore, transition studies need to engage more explicitly with these missing dimensions. Some of the more empirical regional studies literature, in turn, emphasizes the importance of socio-spatial embedding at the expense of socio-technical coherences cutting across different territories and scales. This strategy may be defendable if the socio-technical system under scrutiny is bounded to a particular region and the challenges to regime reconfigurations will play out in the same region. However, sustainability transitions are not likely always to accord to these conditions. It is therefore maintained that both traditions would profit from considering the different aspects in a more balanced way.

**Illustrative research lines**

Obviously the outlined agenda opens up a wide variety of possible research lines on sustainability transitions that cannot possibly be covered in a single paper. The following will be limited to sketching two examples where a geography of transitions agenda could immediately bear fruit. The paper will draw on recent empirical research explicitly positioned at this boundary zone. The first deals primarily with introducing spatial dimensions into the formation of new socio-technical configurations mostly undertaken by transitions scholars. The second addresses the role of cities and regions as strategic sites and actors to promote or even manage sustainability transitions and relates to research recently undertaken by urban and regional studies scholars with an interest in sustainability transitions.

The first illustrative field of enquiry consists of the explicit analysis of formation processes of socio-technical
configurations and their spatial embeddedness. Sustainability transition studies, as reviewed above, often refer rather superficially to spatial contexts in which specific processes are generated. As a consequence, the technology-focused analysis remains partial and the policy implications risk being too simplistic. Recent research on the transitions tradition has started to explore the spatial preconditions for the formation of socio-technical configurations more explicitly. One study using the TIS framework has explained differential growth rates in photovoltaic markets among German federal states. It showed that the ‘formation of markets’ has to be seen as an active social construction process driven by a particular actor constellation: solar civic initiatives. These civil society associations played the role of early ‘system builders’ (Dewald and Truffer, 2011) explicitly limiting their activities to communal contexts in specific German federal states. Solar civic initiatives were founded from the early 1990s onward by politically mobilized citizens but increasingly enrolled professionals (local plumbers, roofers, engineering firms, etc.), government officials and researchers. Their self-defined mission was to develop a market for decentralized photovoltaic panels within their local communities. Market formation consisted of very heterogeneous activities such as building up marketing strategies, setting up system integrators and providers, constructing user profiles, and finally experimenting with support policies for single-house, roof-mounted solar panels, that is, they managed to coordinate the socio-technical embeddedness process. Socio-spatial embeddedness was developed by attempting to require formation processes in a spatially confined institution and actor context. They 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. The study furthermore shows that those federal states with a high share of solar civic initiatives showed stronger market development before the pervasive promotional scheme (a national feed-in tariff for renewable energies) was introduced in 2000. But they also experienced two to three times higher market growth rates throughout the following decade. Therefore, the local formation processes not only led to the establishment of configurations that work, but also created an export base on which the later diffusion process could build (Dewald and Truffer, 2011).

The important conclusion of this study is that local formation processes not only provided an additional explanatory factor for the market growth differentials among federal states. More importantly: without the socio-spatial embedding, the introduction of a national feed-in tariff would have been highly questionable (Jacobsson and Lauber, 2006). Therefore, this study provides an almost ideal type illustration of the importance of local formation processes in a national context of technology development. However, the story should not be interpreted as a standard template of the geography of transition processes. In its core it still represents a rather ‘linear’ diffusion process starting at the local scale and expanding first into federal states and then into Germany as a whole, before global diffusion could be embarked. One reason for this interpretation is that this study strongly focused on the conjoined analysis of socio-technical and spatial embedding. A more encompassing account of the success story of the formation of the German photovoltaic market would additionally have to analyse the politics of market formation and multi-scalar interdependencies. The feed-in tariff would not have been introduced on a national level without the support of constituencies in several federal states that had experienced early market growth and the very active lobbying of certain political actors at the federal level (Jacobsson and Lauber, 2006). Furthermore, with the more recent rise of China as an important exporter of photovoltaic panels, multi-scalar processes have gained considerable importance, which will also impact the framing and acceptability of future promotional policies in Germany. Therefore, actually the photovoltaic market success story in Germany is much less linear than what a superficial reading of Dewald and Truffer’s (2011) work might suggest. Some more recent studies have started to conceptualize multi-scalar geographical substructures in TIS that identify regions in a relational way in the broader context of a global opportunity set (Binz and Truffer, 2011) or by drawing on recent work on global value chains as proposed by Hayter (2008).

A second illustrative example of a productive line of research relates to the role of cities and regions in promoting sustainability transitions by specific policies. This topic has recently been addressed by urban studies researchers (Hodson and Marvin, 2010; Bulkeley et al., 2010) actively engaging with transitions research. In transition studies there is an elaborate literature dealing with the strategic management of technological niches (Hoogma et al., 2002), which implicitly considered local governments as important managers of these niches. Cities and regions may provide protected ‘spaces’, where the usual selection pressures are somewhat moderated and therefore the construction of socio-technical configurations can take place. Many of the transition town movements or other alternative technology movements may be classified under this group (Smith, 2003; Davies and Mullin, 2010; Seyfang and Smith, 2007). Also, green-tech cluster initiatives supporting future regional competitiveness and job growth could be subsumed under this heading (Cooke, 2010; Stormer, 2008).

Empirically, an increasing number of initiatives of cities and regions positioning themselves as sustainability or green-tech leaders are observed. Often these initiatives aim at implementing integrated programmes for sustainable urban living, encompassing a broad range of new technologies such as energy-efficient housing, renewable energies, the efficient use of water, and green public transport policies. An interesting example
Environmental Innovation and Sustainability Transitions in Regional Studies

has been analysed by Carvalho et al. (2011) who showed for the cities of Curitiba, Gothenburg or Hamburg how they managed successfully to gaining recognition as sustainability leaders in their countries and even globally. In the specific technological field, these cities provided a test-bed for the introduction of new technologies (alternative fuel buses in this case) and they became active parts of the respective TIS by interacting with their local industrial competence base consisting of both small and medium-sized enterprises (SMEs) and transnational companies. By this, they were able to play important roles in the innovation process at different scales simultaneously, supporting specific local greener transport solutions that also became available to other cities and regions by directly impacting the decisions of multinational companies. The example shows that cities and regions can become powerful promoters of sustainability transitions when understood as relationally embedded actors and providing crucial resources for successful innovation processes.

In studies on the role of cities in sustainability transitions, obviously power plays an important role as well. Sustainability initiatives should be analysed not only as instrumental policy problems, but also as discursive acts in an ongoing political struggle for resources and as an expression of conflicts of interest in the respective regions. This may explain why cities with high-flying programmes for sustainability may at the same time show very moderate success in their actual environmental and social achievements. As Hodson and Marvin (2011) have convincingly shown, often there is a multitude of actors speaking on behalf of a city’s sustainability ambitions responding to specific expectations of specific constituencies but not addressing the transition challenge in a sufficiently balanced way. The authors show how several specifically appointed programmes have emerged in Manchester claiming to promote a more sustainable city without much 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 the maintenance of predominant regime structures rather than any conceivable change towards a more sustainable city. A balanced geography of transition analysis would thus address the emergence of new socio-technical regime structures, their local embeddedness, scale and power in their interrelation. This would enable geographers and transition scholars to assess critically the plausibility and effectiveness of specific transitions programmes and their likely outcomes.

CONCLUSION

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 programmes, entrepreneurial strategies and citizens movements are more likely to contribute to its ultimate goals. The present paper reviewed strands of the sustainability transitions and the regional studies literature in this respect and it found that both were lacking essential parts to fulfil these aspirations. The regional studies literature is often not sensitive enough to analyse the width of the transformation processes implied by sustainability transitions. This may lead to a biased focus on already locked-in and mature industry structures at the expense of more emergent and experimental configurations that are still to be adopted by and aligned with regulatory environments and markets. Furthermore, there may be an overemphasis of local and regional context conditions for sustainable development that overlook the potential need for major structural shifts more globally. For instance, in connection with sustainable regional development policy there is a substantial risk of limiting the discussion to ‘little victories’ (Haughton and Morgan, 2008). What is at stake, however, is to accelerate policy and practice from an initial ‘niche’ to a large-scale transformation that replaces dominant (unsustainable) practices (Geels et al., 2008). 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.

Given the shared interest in and focus on evolutionary approaches to regional and industrial development, there is considerable scope for cross-fertilization between regional and sustainability transition studies. Both fields acknowledge the pros and cons of path dependence and lock-in. While transition studies brings to bear that these processes may inhibit system shifts towards more sustainable modes of production and consumption, it remains crucial to consider that such path dependencies and lock-ins may display considerable regional variation and, thus, regions are confronted with different potentials for sustainable transformations. At the same time, transition studies’ focus on formative phases of socio-technical configurations may be a resourceful addition in regional studies to understand the scope and extent of variety creation needed to facilitate sustainable transformation processes. What remains integral to combined future research is the need to be sensitive to the historical and spatial contingencies that come to play when scrutinizing efforts and initiatives that seek to support more sustainable configurations in production and consumption. This paper has identified scale and power as important dimensions with which future theoretical and empirical work needs to engage.

The sustainability challenge is most likely here to stay for the coming decades and will therefore not disappear from the regional studies agenda (Martin, 2001). One way to view it is that sustainability merely represents a new version of a very old preoccupation in regional
studies. It relates to the analysis of the consequences of socio-economic 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 hand. Geography and regional studies have 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 for exclusively 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. This is seen as an invitation for scholars from regional studies and economic geography at large to engage in the quest for better concepts and policies, to mainstream sustainability more firmly into the research agenda of this community, and to develop it into a truly mobilizing epistemic project for the discipline.

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NOTES

1. This paper explicitly focuses on the emerging sustainability transitions research community such as defined by van den Bergh et al. (2011) or Smith et al. (2010). This is not to say that they represent the only relevant traditions from which regional studies could get inspiration in their quest for sustainability-related research. Other possible candidates are: various forms of complex system and evolutionary modelling approaches (Van den Bergh et al., 2011), environmental innovation research in the tradition of sectoral systems of innovation and production (Oltra and Saint-Jean, 2009), the role of citizen movement for emerging cleantech industries (for example, Sine and Lee, 2009) or contributions from ecological economics (Castro e Silva and Teixeira, 2011). In order to keep the literature review in this paper within acceptable bounds, the authors have refrained from reviewing the field of sustainability-oriented social science research with a relationship to technological innovation more extensively.

2. For a recent response to these criticisms, see Geels (2011).

3. Following Boschma (2003), a singular conceptualization of proximity equal to geographical proximity is not being referred to, but a relational understanding of proximity which also considers social, institutional, cognitive and organizational proximities is acknowledged.

4. For a similar analysis of biogas technology in Austria, see Spath and Rohracher (2011); or on the emerging wind industry in Denmark and the United States, see Garud and Karnoe (2003). For a similar analysis of the key role of civil society initiatives in the US wind industry, see Sine and Lee (2009).

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