

Breaking out of the national : foundations for a multi-scalar perspective of socio-technical transitions

Citation for published version (APA):

Raven, R. P. J. M., Schot, J. W., & Berkhout, F. (2012). *Breaking out of the national : foundations for a multi-scalar perspective of socio-technical transitions*. (ECIS working paper series; Vol. 201203). Technische Universiteit Eindhoven.

Document status and date:

Published: 01/01/2012

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.



**Breaking out of the national:
Foundations for a multi-scalar perspective
of socio-technical transitions**

Rob Raven, Johan Schot and Frans Berkhout

Working Paper 12.03

Eindhoven Centre for Innovation Studies (ECIS),
School of Innovation Sciences,
Eindhoven University of Technology, The Netherlands

Breaking out of the national: Foundations for a multi-scalar perspective of socio-technical transitions

Rob Raven^{a*}, Johan Schot^a, Frans Berkhout^b

^aSchool of Innovation Sciences, Eindhoven University of Technology, PO Box 513, Den Dolech 2, 5600 MB, Eindhoven, The Netherlands

^bInstitute for Environmental Studies, VU University Amsterdam, De Boelelaan 1085, 1081 HV, Amsterdam, The Netherlands

*Corresponding author: (E: r.p.j.m.raven@tue.nl; T: 0031 40 247 4413; F: 0031 40 244 4602)

Abstract

The multi-level perspective (MLP) is a widely-adopted framework for analysing stability, change and transitions in socio-technical systems. Key to explanations of change is the interaction between nested levels (niche, regime, landscape) constituting socio-technical systems over time. This paper proposes a second generation MLP that explicitly incorporates a spatial dimension. Recent developments in innovation studies and contributions from regional studies and geography are reviewed. We draw on notions of space as being relational, fluid and contested by institutionally-situated actors. Dynamics in socio-technical systems are explained not only by interactions between modes of structuration and developments over time, but also by interactions between actors and institutions situated across different levels of spatial scale. The paper re-visits an existing case study of biomass gasification in India to show the kinds of insights that might emerge from adopting a second generation MLP to socio-technical system dynamics.

Key words

Socio-technical systems, multilevel perspective, transition, multi-scalar, transnational

1. Introduction

The literature on socio-technical transitions documents many case studies. Almost all of these studies assume a national setting. Denmark is an often cited example for its pioneering role in the development of wind turbines (cf. Garud and Karnoe, 2003; Kamp et al, 2004) and biogas (cf. Geels and Raven, 2007); Germany is well-known for its leading role in many renewable energy technologies (cf. Jacobsson and Lauber, 2006); the Netherlands is credited for applying a transition management approach in energy (cf. Kern and Smith, 2008; Loorbach, 2007), or for failing in the development of renewable energy technologies (cf. Geels and Raven, 2006; Negro et al, 2008); Sweden is seen as an example in the development of biofuels (cf. Hillman et al, 2008); India has achieved some success in the development of biomass gasification technologies (Verbong et al, 2010); and so on. These studies suggest (often implicitly) that the national is the right geographical delineation for understanding sustainability transitions. This becomes also clear when we look at 446 papers published in the transition studies field since the mid-1990s (Figure 1).

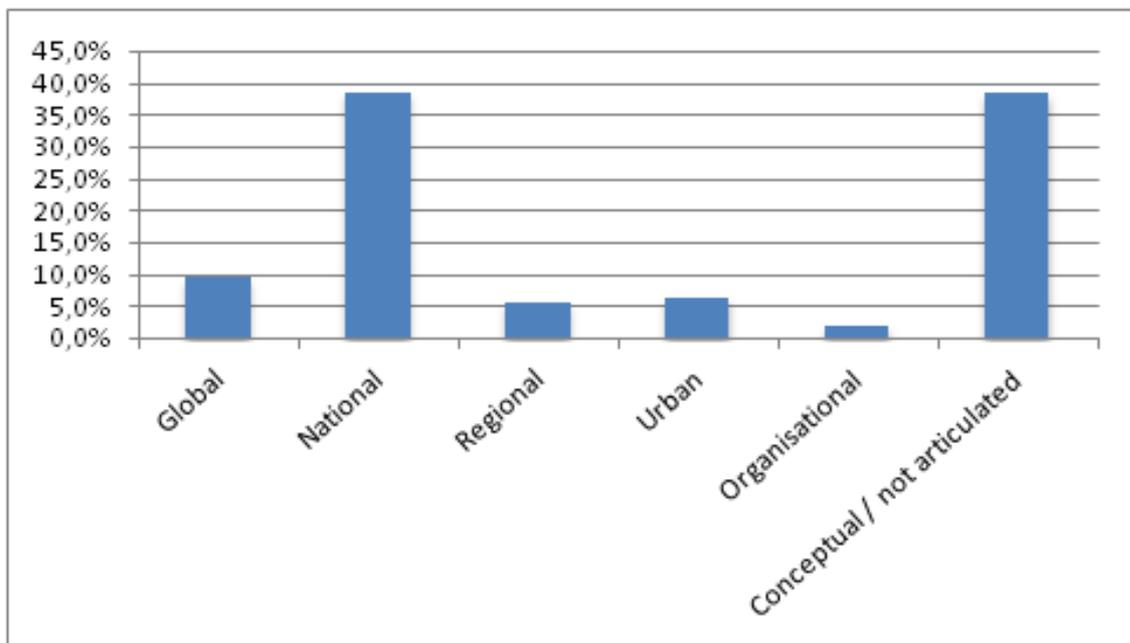


Figure 1. Distribution of the geographical unit of analysis in papers published in the field of transition studies in the period 1994-2011. “Global” studies take the world, continents or ‘developing countries’ as its unit of analysis. “National” studies delimit their empirical analysis to a specific country. “Regional” provide a sub-national focus (such as states in the US or India). “Urban” studies focus on cities. Finally, a number of papers focus on firms as main unit of analysis. “Conceptual/not articulated” are largely “theory” papers with no explicit reference to a spatial level (source: Markard et al., 2012).

This framing of transitions in national settings is at odds with scholarship in innovation studies which has investigated the internationalisation of science, technology and innovation (Howells, 1990; Archibugi and Michie, 1997; Pavitt and Patel, 1999; Carlsson, 2003), and in regional studies and economic geography which has placed caveats by the focus on national contexts for innovation, arguing that actors and institutions at multiple spatial levels interact to create 'spaces for innovation' (Amin and Thrift, 1992; Storper, 1997; Bunnell and Coe, 2001; Amin, 2002; Sunley, 2008).

The multi-level perspective (MLP) currently conceptualizes transitions as the outcome of interactions between three 'levels': regimes, niches and landscapes that describe socio-technical systems. At its heart these levels correspond with variations along two scales: a temporal and a structural scale. The spatial scale of socio-technical systems is not explicitly conceptualised. In the context of globalization and regionalisation this may lead to simplistic or incorrect analytical assumptions and empirical analysis. Indeed, empirically the three levels (niche, regime and landscape) are often implicitly conflated with specific territorial boundaries: regimes tend to be depicted with national features (these being the focus of much empirical research); landscape dynamics with international features; and niches with (sub-)national or local features.

Theoretically, however, there is no reason to conflate the MLP levels with specific territorial boundaries. The MLP levels refer to processes with different temporal dimensions and modes of structuration that could each have a variety of spatial positionings and reach. In niches, social networks are less extensive, less stable, expectations more fragile, and learning process are less institutionalised than in regimes, but such networks need not be exclusively local. Likewise, socio-technical regimes may be transnational in physical extent, in the institutions that constitute them, or in the economic and technological base that supports them, or, conversely, remain regional or local in their spatial reach. For most regimes that are significant for sustainability, national territories are certainly not the only salient space.

Yet it remains unclear how to incorporate spatiality into the MLP and in transition studies more generally. Recently this has generated a new debate from a growing community of scholars in, regional studies, economic geography, human geography, political ecology and international environmental governance (cf. Coenen et al, 2012; Lawhon and Murphy, 2012; Bulkeley et al., 2011; Truffer and Coenen, 2012; Monstadt, 2009; Hodson and Marvin, 2009; 2010). While being effective critiques, these contributions have not yet resulted in a

reconceptualization of the MLP. In this paper, we make a proposal for incorporating a theorised conception of spatial scale into the MLP.¹

We propose a second generation or ‘three-dimensional’ (3D) MLP that explicitly incorporates not only structure and time, but a conception of space. This movement towards a spatially-explicit MLP is important since we contend that any transition to sustainable development will require interaction between spatially-distributed actors, institutions and economic structures that exercise power within and across heterogeneous and uneven spaces of innovation (Bunnell and Coe, 2001). A consideration of spatial scale introduces a number of new dimensions to the analysis of socio-technical systems: *distance* (or proximity) as a factor in innovative activity; *spatial differentiation*, from the observation that different places, however defined, exhibit niches, regimes and landscapes with different characteristics; and *reach*, the observation that ‘action at a distance’ operates in social systems across scales and levels.

We propose that transitions need to be explained by taking into account developments over time, interactions between different modes of structuration, and interactions between spatially-distributed but connected actors and transition contexts (from local to global). In short, we propose a *multi-scalar MLP*, including a theorisation of time, structuration across levels and of spatial relationships. We note that notions of scale, level and space are used ambiguously within and across different disciplines. Here we will follow Gibson et al (2000) and define scale as the analytical dimension used to measure and study any phenomenon (e.g. time, structure and space). Scales find expression in ranges (years and decades, niches and regimes, local and global). In the analysis of social structure and action these scalar ranges or levels are held to stand in dynamic interaction with each other (for instance, actors may act over periods of years, and do so in response to expectations over a decade or more). Space can be physical, such as in a territorially bounded place (e.g. a village, region or country). Or space may be seen as being *relational*, in the sense of emerging out of a structured interaction between social or economic entities (Massey et al., 1999). Space therefore has many manifestations besides the physical, and its main value in the analysis of socio-technical change is in providing a means of representing unevenness, heterogeneity and asymmetry in socio-technical systems. Multi-scalarity therefore refers both to the existence of different scales (time, structure, space), as well as different levels along these scales. A three-dimensional MLP is therefore concerned with an extension in the number of interactions that need to be considered. We will elaborate on these scales and levels in the next sections.

¹ See also Smith et al. (2010:443). In his response to seven criticisms on the MLP, Geels (2011) does not respond to criticisms related to assuming national boundaries around regimes, or lack of spatial sensitivity in the MLP.

In the following section we start by discussing the inspirations for and theorisations of the current two scales in the MLP: time and structure. We continue by discussing recent contributions from regional studies and geography. In the fourth section we propose how a spatial scale can be introduced into the MLP. The fifth section highlights four research topics by revisiting a published empirical case study on the development of the Indian biomass gasification niche. The paper ends with conclusions.

2. Current scales and levels in MLP

The MLP is rooted in the historical analysis of technological change, and concerned with the interactions between agency and structure across levels (niches, regimes, landscapes). We summarise these two inspirations here and focus on the resulting scales and levels incorporated in the MLP. The aim is not a complete rehash of the MLP, which has been done elsewhere (Rip and Kemp, 1998; Geels, 2002; Grin et al., 2010).

The MLP is a quasi-evolutionary theory that is much concerned with the role of time in innovation processes inspired by historical studies of technological change (Geels and Schot, 2007). History is a discipline concerned with chronology and the accumulation of actions and beliefs through time. Its main objective is understanding change over time. Hence historians often debate periodization, and, for example, whether World War II or other similar big events should be seen as an historical divide in world history. Braudel (1982), and many historians who followed him, developed the idea that time is heterogeneous and hence history unfolds on different levels of time. Braudel had his own specific interpretation of three temporal levels, from events, to conjunctures, to the *longue durée*. The development of the MLP translated these ideas in the following three temporal levels: events, institutions, and slow-changing structures and resulting trends. Events have a short-time span. These are the new developments in projects, the reshaping of alliances and the change of expectations often discussed in the corridors of professional conferences and the polity.

Besides events, history is influenced by changes of institutions, cultural repertoires and market structures, which do not change quickly and hence operate on another temporal level. Finally we have slow-changing structures, for example deep-seated trends such as economic growth, demographic change or social processes which can be punctuated by major events, such as wars or natural disasters. This translation of Braudel's idea of levels of time shaped the MLP used in transition studies (Rip and Kemp 1998; Schot 1998; Geels 2002). Braudel

never developed a clear picture on the relationships between these three temporal levels.² For him they were layers of time, each with their own history. The MLP integrated these temporal levels into its three levels that are deemed to interact and structure each other in a specific way. Transitions come about through a specific pattern of temporal interactions between niches, regimes and landscapes (Geels and Schot, 2007; Smith et al., 2005), which does not refer to the usual micro-meso- macro distinction often applied in social and economic analysis.

A second scale was inspired by the neo-institutional structuration theory of Giddens (Giddens, 1984), which is concerned with ways in which actors' values, capabilities and actions come to be ordered by the structures in which they are embedded, and which in turn reproduce and transform those structures. Consequently, socio-technical regimes are understood as both the medium and outcome of action ('duality of structure'): "On the one hand, actors enact, instantiate and draw upon rules in concrete actions in local practices; on the other hand, rules configure actors. Examples of regime rules are cognitive routines and shared beliefs, capabilities and competences, lifestyles and user practices, favorable institutional arrangements and regulations, and legally binding contracts." (Geels, 2011:27).

In the MLP these notions of structuration and enactment are not only constitutive for regimes, but also for niches and socio-technical landscapes. It was recognized that not all structures have the same degree of order and stability and that this influences the behavior of actors. In other words, the niche, regime and landscape levels represent an increasing degree of ordering, but also a different mode of structuration of practices. Niches are protective spaces in which actors have relatively more agency and freedom (but limited power) to develop new routines and enact alternative structures such as new codes of conduct, routines, visions, standards, norms that deviate from the mainstream. In the case of regimes, the balance shifts towards stability. Routines are stabilized and embedded in broader organizational systems, networks and infrastructures, which makes it less likely that actors can escape their structuring impact. At the same time such ordering provides regimes with their durability and regime actors with systemic, predictable and effective influence. Regimes provide rule-sets, which orient actor behavior. The landscape is conceptualized as an exogenous environment that actors cannot influence in the short term, but only adapt to. Of course, in the long-term, due to regime-changes that emerge as an outcome of changing actor practices, landscapes will also move. This structuration is different from the one provided by niches and regimes. It

² Some question this multi-layered thinking of time and argue that slow and rapid processes of change can occur everywhere, i.e. in niches, regimes and landscape. 'Niche' practices might be durable for centuries while landscape processes can change rapidly (Hyysalo, 2010:48; Jorgensen, 2012).

literally relates to a landscape that makes certain directions more risky, costly and difficult than others. Actors can choose to fight an up-hill battle by working against dominant long-term structures, but they often will decide to go with the flow.

The following table summarises the discussion above. In the current MLP, niche, regime and landscape concepts correspond with three levels on two different scales (time and structure). At the niche level, the temporal scale typically involves innovation processes in the range 0-10 years. Regimes on the other hand are characterised by change processes taking multiple decades up to fifty years, while landscapes represent the ‘long durée’ (centuries) sometimes punctuated by events such as wars and disasters. Note that change of regime or landscape may happen in a relatively short period of time, however within the MLP it is assumed that these changes unfold over a much longer time period. From a structural perspective, the niche represents a protective space due to which actors have relatively more agency to experiment with alternative practices and institutions. The regime level is represented as endogenous structures enacted by extensive organisational networks and embedded in infrastructures that orient (constrains and enables) actor’s behaviour. Regimes provide actors with heuristics or routines. Finally, the landscape offers high structural constraints and enablers. It provides no room for agency, actors can only respond to it. In other words it is an exogenous environment for regimes and niches.

Table 1: scales and levels in a 2D MLP

MLP concept	Time	Structure
Landscape	Long durée, sometimes rapid change caused by disruptive events	Exogenous Environment
Regime	Decades	Endogenous institutional structures enacted by extensive organisational networks and embedded in infrastructures
Niche	0-10 years	Actors have relatively much agency to develop alternative practices and institutions within protective spaces.

3. Critiques of the treatment of space and place in the transitions literature

Geographers have made a number of contributions to the notions of scale, place and space in the field of transitions studies. Coenen et al. (2012) and Truffer and Coenen (2012), in a discussion about the lack of a spatial dimension in transition framework, argue that the MLP falls short in a number of ways. First they argue that the national level is reified in transition studies. Second they show that regimes tend to be depicted as homogenous structures and do not take into account local variations and interpretations (see also Dewald and Truffer, 2011 and Lawhon and Murphy, 2011). Third they point out that niche development is determined not only by the development of actor networks, expectations and learning, but also by the specificities of the place and uneven endowments and access to innovative capabilities and resources. By not paying enough attention to local diversity, interpretations and institutional contexts (on a regional, city or neighborhood level), the MLP has difficulty explaining why niches emerge in one place and not in others. We share this criticism, however, we do want to point out that the very notion of niches assumes specific local conditions that allow particular innovations to emerge. Hence, there is a sense of the importance of local conditions within the MLP, however, these conditions are not sufficiently taken into account in the empirical analyses inspired by MLP.

Hodson, Marvin and others have also questioned the lack of geographical sensitivity in the MLP (Hodson and Marvin, 2009; 2010). Their work deals with the role of urban and regional processes in shaping socio-technical transitions. They argue that responsibilities for key aspects of technology, innovation and competitiveness policies have increasingly been transferred from being a national concern (Porter, 1990) to cities (and in particular they refer to 'world-class' cities in the West). Hodson and Marvin address the question of how this re-emergence of the city should be conceptualized in the MLP. Are cities and regions simply sites where niches are developed in response to a national regime? Do cities actively seek to 'pull down' landscape pressures and appropriate them to their local contexts? Or do cities represent their own regimes within which niches and transitions unfold? Our response is that the answer can vary depending on the nature of the regime, whether regional regimes are nested in national regimes, which in turn are nested in transnational ones. In this, they are following a tradition in economic geography. Amin and Thrift (1992) for instance argued for the importance of regions as 'nodes in global networks' of innovative activity. The main question is whether transnational interactions between global cities are becoming an important arena for the creation and expansion of niches, generating the conditions for regime-shifts?

Spatial scale is also highlighted in the work of Lawhon and Murphy (2011) and Monstadt (2009), who mobilise political ecology to draw attention to limited conceptualisations of power

relations in transnational urban networks and international environmental decision-making. According to Hodson and Marvin (2010), specialist intermediaries working in city contexts mediate between different social interests, operating at various levels (neighborhood, city, national, international), selectively and strategically coupling different networks and accessing resources available across different levels. John Grin et al. (2010) also argues for the ability of actors to mediate between different levels and enact transitions. We believe such approaches to spatial scale and levels and the social networks that constitute them contains an important lesson for a multi-scalar MLP.

A similar focus on spatial scale and levels is visible in the work of Harriet Bulkeley and Michele Betsill (2005, 2006). They also study the role of city administrations, use a multi-level governance perspective and engage with transitions research (see also Bulkeley et al, 2011). They criticize the current environmental politics literature for assuming global, national and local environmental politics as taking place in isolation of each other. Besides discussing how individual cities respond to and engage in multi-level governance in the context of climate change, they also discuss transnational networks formed by city administrations. These networks, consisting of both state and non-state actors, are seen as new forms of governance, complementing traditional local, national and international levels of governance. These new governance networks interact with and cut across traditional state structures and processes of governance. Rather than choosing between levels or scales of analysis, Bulkeley and Betsill argue for a renewed approach to environmental politics that foregrounds such hybrid and emergent networks.

Three types of transnational networks are distinguished. *Epistemic communities* are networks of experts who share a common understanding of the scientific and political nature of a particular problem, and who receive increasing attention by virtue of their authoritative claims to knowledge. *Transnational advocacy networks* include ‘...those relevant actors working internationally on an issue, who are bound together by shared values, a common discourse, and dense exchange of information and services’ (Haas, 1990:55, quoted in Betsill and Bulkeley, 2005). They are seen to derive power by ‘...using their information, ideas and strategies to alter the information and value contexts within which states make policies’ (Keck and Sikkink, 1998:16, quoted in Betsill and Bulkeley, 2005). The third form of transnational networks - *global civil society* – is concerned with the multiplicity of actors and institutions that influence the ways in which global environmental issues are addressed *across levels*. These networks are seen to be an important site for governing global environmental action in their own right.

Recently, historical studies have also developed more attention for the spatial dimension of change through time. This is partly a result of a new understanding of the process of globalization. Historians have criticized social scientists for assuming the existence of an unlimited space of global flows while analysis shows that globalization happens in specific corridors or spaces, excluding many other spaces, organisations and people. Many people stay disconnected (or are excluded by globalization processes) while others become connected. This has led to a rethinking of the notion of global space, and the understanding that it is impossible to distinguish between an inner space of a national context (or city or region), and an outer space of the world outside the national context.

Actors are viewed as being framed and acting at multiple and interacting spatial levels, but their positioning is reinforced as globalization unfolds. People not only move from one level to another, they belong and act simultaneously in and across different levels. Examining local practices shows how much certain developments, which appear to be determined by local circumstances, are imbued with inputs from other places created through circulation of people, ideas, and goods. These circulations and connections cut through levels, leading to a relational idea of action and change. This framing has led to the idea of multiple and interacting spatial levels and to research on how the local and global interact to constitute and transform each other (Saunier 2008; Vleuten 2008; Vleuten and Høgselius, 2012).

This research also generated a new understanding of the notion of space itself. Space is not simply about physical territoriality. Space is also constructed space, created through physical, economic and social networks. Interactions and representations are multilayered, in which boundaries are contingent and continually negotiated and revised. Space has meaning only in relation to the perceptions of actors, and to their interests and strategies. This critique echoes the relational school of economic geography, which is concerned with power relations between actors positioned across different spatial levels and how these relations influence opportunities and processes of change (Cox, 1998; Brenner, 2001; Sheppard, 2002; Hess, 2004). 'Socio-spatial' relations between actors are seen as being intertwined with processes of economic and institutional change at different spatial levels (Boggs and Rantisi, 2003; Massey, 2004; Yeung, 2005). Hence actors do work to control and stabilize the many different real and imagined spaces that have value for them (Müller and Torp 2009). Historians have drawn the conclusion that analysis should not only focus on the ways in which developments in local spaces (however defined) are influenced by their embedding into more global spaces. Analysis should also look at the imagined spaces, the struggles and conflicts in establishing specific spatial relationships and the resulting regimes and institutions, and implied reorganizations of spatial relationships.

Finally, we discuss research on the role of the region as a site of innovation (see Bunnell and Coe (2001) for a review). This literature is concerned with understanding the paradox of globalization on the one hand and the increased significance of regions on the other (Coe et al, 2004). Regional economic development is explained by the entwining of connections between processes and factors endogenous to a region (such as local labour forces, regional institutions or tacit knowledge) with the strategic needs and assets of 'trans-local' actors, such as transnational corporations embedded in 'global production networks' (Coe et al., 2004; Henderson et al., 2002, Ernst and Kim, 2002). A relational approach is taken which emphasizes connections between local and trans-local features of firms, labour, technology, regulations and finance and the flows through these connections. It is argued that the (mis)fit between local and trans-local relationships explain the ways in which regions are developing. This is always a negotiated fit, in which power differences and strategic games play an important role. Trans-local actors might threaten with 'spatial switching' between regions while local actors will strategically exploit the regional assets important to trans-local actors (Massey, 1984; Amin and Thrift, 1992).

Bunnell and Coe (2001) conclude that the "...key argument is that the study of 'spaces of innovation' needs to be more oriented towards exploring the linkages and interrelationships *between* and *across* these various spatial levels or scales, from the 'regional/local' through to the 'global'" (Bunnell and Coe, 2001:577). They propose that tracing networks between actors is necessary to understand spatiality in innovation processes (see Sunley, 2008 for a critique). Instead of focusing on the scale at which innovation is taking place, what needs to be done is to trace continuities across different spatial levels, i.e. from one locale to the next (see also Latour, 2005), and to study how such connections support or disrupt spaces for innovations. This relational perspective to innovation holds an important lesson for a 'spatialized' MLP. It suggests that a spatial perspective should adopt a relational perspective emphasizing networks that are enacted and structured across different levels of spatial scale.

This discussion shows that a case can be made for a multi-scalar MLP in which besides time and structure, space becomes a scale that is taken account of in analysing order and change in socio-technical systems. Important regime dimensions such as governance, value chains, production systems, markets, infrastructures, culture and research networks all have important transnational, as well as sub-national and local dimensions, besides national ones. Such a multi-scalar account assumes that actors, institutions, beliefs and practices at all levels are embedded and entwined in broader transnational and sub-national spaces of innovation.

4. Developing a multi-scalar model of socio-technical transitions

A *second-generation, three-dimensional MLP* envisages the addition of a spatial scale to the MLP complementing time and structure. Following Gibson et al. (2000) we distinguish between two potential ways of including a spatial scale into the MLP: an *absolute* spatial scale and a *relative* spatial scale. Based on our discussion so far, we propose that the relative spatial scale is the most promising one for advancing the MLP. We will propose a framework to include spatial scale and levels into the MLP based on an extension of table 1 and sketch the outlines of a number of perspectives and processes of a 3D MLP framework to illustrate some of the potential dynamics of a 3D MLP.

Adding a spatial scale to the MLP requires defining a spatial scale, as well as the levels along that scale. Gibson et al. (2000) argue that an absolute spatial scale refers to cities, regions, nations, and so on as containers of spatial variables that explain transitions. Spatial scale is defined as a territory, and territorial factors and processes are added as an explanatory variable to understanding transitions. Hence, in the case of an absolute spatial scale, territorially-bounded institutions, labour forces, resources and so on become part of the explanation of how and why a transition or niche innovation occurs in a particular place and not in another. Drawing on Yeung (2005) we may argue that this refers to an approach in economic geography that is concerned with 'relational assets' in local and regional development. Relational assets are social relations, conventions and endowments in a particular locality or region that are slow to reproduce and may be impossible to imitate. They provide a relatively durable base for relative and comparative advantage, including knowledge, skills and other resources such as capital, but also the 'institutional thickness' (Amin and Thrift, 1994), identity and social capital that shape relationships in a given place.

Economic geographers have traditionally emphasised the importance of proximity and co-location for learning, knowledge creation and innovation, but in doing so have pointed to other forms of proximity. *Cognitive* proximity refers to the shared knowledge base between actors. *Organizational* proximity refers to a similar organizational background of actors. *Social* proximity refers to levels of trust, friendship, kinship and experiences between actors. Finally, *institutional* proximity refers to the extent at which actors have similar broader cultural backgrounds such as societal norms and values. Boschma (2005) argues that these forms of relative proximity weaken geographical (absolute) proximity as a necessary precondition for learning and innovation. Proximity is itself multidimensional, taking several nested and intersecting forms, influencing the position, practices and power of economic actors.

In a first attempt, Coenen, Raven and Verbong (2010) have suggested that such notions of proximity are relevant for making Strategic Niche Management spatially more sensitive. Taking this typology we propose that a relative spatial scale can be included in the MLP by distinguishing between niches, regimes and landscapes as socio-technical networks with different levels of relative proximity and power. Niches are characterised by networks of actors with low levels of relative proximity and power in emerging socio-technical systems. Their short histories have not yet led to dense networks with strong social, institutional, organisational and cognitive relationships among its nodes. Regimes are characterised by networks of actors, which due to longer developmental histories exhibit high levels of relative proximity and power within incumbent socio-technical systems. Finally, the landscape is characterised by networks of actors with high levels of proximity and power *across* incumbent socio-technical systems.

An alternative is to think of spatial scale as being relative. In this case, spatial scales are socially constructed through networks of actors and cut across territories. Viewing spatial scales as relative implies that the absolute spatial reach of niches, regimes and landscapes is not taken for granted upfront. Instead, actors are theorised as being connected and standing in relation with each other, creating and reconfiguring networks and power within these networks, causing knowledge, resources, technologies and innovations to flow. Space itself is not a given in this view, but socially defined, reproduced and redefined. As such, transitions do not simply occur within a certain territorially bounded space (e.g. a country), but emerge out of the tensions created in multi-scalar interactions between spatially distributed actors embedded in multi-level structures with different temporal dynamics.

For Yeung (2005), this perspective relates to a strand in economic geography that sees the geographical scale in terms of relational constructions (the local always standing in relation to the national and the global, for instance) and social relations as scalar constructs (social relations being constituted across space and scale through the effective use of power). This perspective is much concerned with interpreting the unevenness and heterogeneity of economic development by understanding the exercise of power as a relational and emergent construct. Citing Yeung (2005: 45):

‘...power is both a relational and an emergent construct manifested through practice. Power is a relational attribute because its effects are experienced through the process of its mobilization and practice. For example, we think of an actor as powerful or having power when we know of prior outcomes arising from the structures of

relations in which this actor is embedded. This actor can be deemed to possess a capacity to act within those structures of relations. Its power is dependent on the fact that this capacity is exercised eventually and successfully.'

Each of these perspectives can enrich the MLP framework. The notions of relational assets as essential but hard to produce institutional and social conditions of actor relationships in a locality can strengthen understanding of the emergence of socio-technical niches. Niches may be seen as spaces in which relational assets are being created, but niches are also more likely to emerge in settings where the kinds of relational assets needed for radical innovations already exist. We would expect these relational assets to be unevenly distributed. Niches do not emerge out of nowhere.

The notion of relative or relational scales offers a means of reframing the scales intrinsic to the MLP as social constructs constituted by organisational and actor relationships that are multi-scalar. Here an analysis of power operating across networks offers new perspectives for understanding niches, regimes and landscapes (Avelino, 2011). An analysis of power and how this explains unevenness in the locus, pace and nature of system innovation is under-developed in the MLP framework (Smith et al., 2005; Shove and Walker, 2007; Meadowcroft, 2009). By introducing another way of theorising power in actor networks, the notion of relational scale may provide a way of better explaining the unevenness of socio-technical development which national empirical research appears only very partially able to do.

Table 2 summarises how the spatial scale can be included as a third scale into the MLP.

Table 2: Scales in a three-dimensional MLP

MLP level	Time	Structure	Space
Landscape	Long durée, sometimes rapid change caused by disruptive events	Exogenous Environment	Typical landscape networks exhibit high degrees of proximity and power across incumbent socio-technical system
Regime	Decades	Endogenous institutional structures enacted by extensive organisational networks and embedded in infrastructures	Typical regime networks exhibit high degrees of proximity and power within an incumbent socio-technical system
Niche	0-10 years	Actors have relatively much agency to develop alternative practices and	Typical niche networks exhibit low degrees of proximity and power within an emerging socio-

		institutions within protective spaces.	technical system
--	--	--	------------------

We attempt to summarise how these perspectives can generate new insights about transition processes in a multi-scalar 3D multi-level perspective (see Textbox 1). The proposed framework and hypothesised dynamic relationships will need further empirical scrutiny, which is beyond the scope of this paper. By way of illustration we will, in the next section, work through an empirical example with the goal of highlighting four potential research directions: 1) more variety in transition pathways; 2) developing an improved theory of multi-level linkages; 3) undertaking transnational transition analysis; 4) unpacking landscape factors and processes.

Textbox 1: some examples of transition processes that are framed in a 3D MLP

1. Transitions evolve through a process of multi-scalar interactions (time, structure, space);
2. The spatial reach of niches, regimes and landscapes is not a given. Space is always negotiated and constructed by networks of actors;
3. Actor networks allow for the distribution of flows such as knowledge, money and natural resources between socio-spatial locations.
4. Socio-technical regimes are nested both horizontally and vertically (for instance, electricity regimes have national, international and regional features and specificities (vertically nested), as well as exhibiting horizontal differentiation between regimes for households, large industries and so on (horizontally nested);
5. The multi-level nesting of regimes is a source for tensions and misalignments, which can be mobilized by actors in attempts to vision and innovate alternative spaces (niches);
6. Nested regimes have spatially-differentiated features; specific niches are more likely to materialize in reconfigured networks and infrastructures in some places than in others, which offer initial spaces for innovative practices;
7. Spatially-situated niches can become (inter)nationally connected through existing or new networks, and reconfigure the flows constituting them and the institutions developed to regulate them;
8. To trace how these new connections are made, by whom, when and where are of particular importance for a multi-scalar analysis, because it would provide insight into how and where niches may be upscaled and come to shape regime-shifts;
9. Niches can also remain localized initiatives and stabilize into sub-national regimes, when they stay disconnected from (inter)national spaces, or become international niches when they become connected, but fail to reconfigure existing regimes;
10. Socio-technical landscapes tend to be transnational since they are the results of choices made in many spatially-distributed and (partially) connected regimes. Yet, at the same time, landscapes might be perceived differently by spatially separated regime and niche actors and therefore exert a different influence over their development.

5. Working through an empirical example

Biomass gasification in India

In a previous study one of us evaluated how biomass gasification technology has evolved since its original conception in the Indian context in the early 1980s to the present day (Verbong et al., 2011). This is a 'first-generation' study from a strategic niche management perspective, including an analysis of internal niche processes (articulation of expectations, learning and actor network formation), an appreciation of regime characteristics that influence the upscaling of gasification technologies, and an assessment of broader landscape developments. In this section, we first summarize the results of that study, with the aim of opening it up to new questions that arise from a multi-scalar approach.

As in most MLP and SNM studies, Verbong et al. (2011) start their analysis of the development of biomass gasification in India by dividing development into several sub periods (following the underlying notion in MLP that time is a distinctive variable). The first period (1980-1987) is characterized as a period of laboratory experimentation. Several Indian research institutes were involved: the Indian Institute of Science (IISc) in Bangalore in the state of Karnataka (South of India), Sardar Patel Renewable Energy Institute (SPHERI) in the state of Gujarat (West of India) and the Indian Institute of Technology (IIT) in New Delhi (North). IISc developed a first prototype of a downdraft gasifier. The prototype, using a dual fuel system that combined biomass gasification with diesel combustion, was first applied in 1987 in pilot projects for pumping water and for power generation.

Verbong et al. signal this as the start of the second phase: large-scale implementation between 1987 and 1993. The Indian national government, through its department of Non-Conventional Energy Sources, implemented a National Biomass Gasifier Programme (NBGP), which heavily subsidized the projects (between 40-100%). Between 1987 and 1993 a total of 1370 gasifiers are installed for water pumping and for small and medium sized power generation, mainly in rural areas so to provide those with access to power. One larger-sized system was installed on the remote Andaman Island in the middle of the Bay of Bengal. Three firms – both with close links with the research institutes – supplied the systems. After several years of experimentation, several evaluations showed that the performance of the gasifiers is very disappointing with very short life spans.

The third phase starts in 1993 and ends in 2000 and is characterized as a process of niche branching. A political and economic crisis in the early 1990s forced the Indian Government to

accept international support, which included World Bank demands for reforms of the Indian power sector. The NBGP is affected, with less support available for individual gasifiers and a decline in numbers of gasifiers built. But the scale of gasifiers increased, and application domains shifted. Now the focus was on captive power generation in industries with biomass resources (e.g. paper production), thermal applications (flower drying, silk reeling, salt extraction, herbs), and for village electrification in rural areas.

The historical overview of niche development ends with a discussion of the developments after 2000, which is coined as 'up-scaling towards commercial systems'. In this phase a significant number of gasifiers is added and a number of producers enter the market. In terms of application domains, the focus is now on rural users (village electrification), industry (mainly heating), municipalities (crematoria) and educational institutes (teaching and engineering purposes).

The pattern of niche branching through different application domains (with ambiguous outcomes) described above is subsequently analyzed through the changes of expectations, networking, learning and regime influences upon the niche. It is concluded that research institutes and producers dominated the social network driving the niche. The national government played a substantial role through funding programs. Users were considered consumers, rather than active participants in technology and niche development. Expectation dynamics are also evaluated as favourable for niche development: niche actors were able continuously to produce positive expectations that were concerned as legitimate by potential funders. Learning is considered the most problematic process in this case, as niche advocates were not been able to move beyond techno-economic learning. Important learning lessons articulated by academics and in evaluation reports about the need for training and maintenance facilities, as well as the role of local culture and power structures, were either ignored or not translated into socio-technical design adaptations of new projects. Finally, a brief regime analysis adds to the evaluation the notion that the current Indian electricity regime is facing many problems, because of poor infrastructures, heavy subsidizing of fossil-fuel electricity, theft of electricity, political inertia in executing reforms, overall slow and hierarchical bureaucracy, and poor management capacity of utilities. This poorly-performing and vulnerable regime is considered not just to provide opportunities for breakthrough, but also to complicate the development of grid-connected gasification power plants, due to the many institutional barriers and uncertainties for investors and end-users.

This analysis aims to explain the development and outcome of niche development through internal niche processes and interactions with the wider regime and landscape contexts. The

study takes time to be a critical variable to structure the narrative and analysis. Finally, it takes 'India' as the unit of analysis.

Spatial variety in transition pathways

Given our discussions so far, what observations and new questions emerge? An important question is to what extent there was spatial variety in transition pathways and why? Or in other words, asking the question *where* did biomass gasification emerge, rather than by whom or when. The above analysis of biomass gasification discusses this question by focusing on a process of *functional* niche branching. The 'where' is answered through the notion of application domains. Little attention is paid to the spatial reach of the networks, flows and activities that underpin the emerging niches. Figure 2 shows that currently operating biomass gasifiers are largely concentrated in a small number of Indian States. Four states have been especially prominent and together represent almost three quarters of total installed gasifiers: Karnataka (476 gasifiers, 28% of Indian total), Maharashtra (316 gasifiers, 18% of Indian total), Gujarat (237 gasifiers, 14% of Indian total) and Andhra Pradesh (231, 13% of Indian total)



Figure 2. Geographical distribution of gasifiers in India. Source data: Buragohain et al (2010)

The figure suggests that taking India as a natural unit of analysis appears to hide important spatial heterogeneity in the dynamics of niche development. Why did these states come to dominate the application of biomass gasifiers? A part of the answer could be geographical proximity. The research institute (IISc), which has been an important actor in the biomass gasification case study, is located in Karnataka. But that does not explain why a biomass gasification socio-technical system became established in Karnataka and in neighbouring states. Indeed, we would need to trace the spatial expression of the social actor networks beyond the niches themselves, including all those generating resources significant to the emergence and reproduction of the niches. These would include connections that are physically proximate as well as those that are non-local. They would also include networks and conditions that were enabling and those that constraining. We would be concerned with the natural, economic, institutional and other endowments – the relational assets - that have influenced the emergent biomass niches, and their spatial distribution.

Natural endowments in terms of the availability of natural resources, appear important in relation to biomass resources as fuel input. The Biomass Resources Atlas of India³ suggests that states leading biogas development also have relatively good biomass resources. However, other states with equal or larger resources such as Uttar Pradesh and Punjab have lagged in developing gasification technologies. Policy or institutional endowments may be important, since the four states leading in biomass generally also have been successful in developing other renewable energy technologies. Karnataka produces more than 20% of its power from renewable resources (Buragohain et al., 2010).⁴ One explanation is that there is considerable *diversity* in state-level electricity regimes. While India's 2003 Electricity Act requires all state-level regulatory commissions to encourage procurement of renewable electricity, some states, including Karnataka, have more aggressive renewable targets (Lewis, 2007). A 3D MLP analysis of biomass gasification would include an analysis of how these state-level regimes are connected and nested in national and international energy regimes, as well as include other state-level arrangements and levels of cognitive, organisational, social and institutional proximity between research, industry, users and policy actors. Beyond this, there may be value in looking at the more local contexts of the biogas initiatives to investigate locational assets and embeddedness of key actors beyond the biogas niche.

Multi-level linkages

³ <http://lab.cgpl.iisc.ernet.in/Atlas>

⁴ Compared to many European countries this is a very large number, in particular when considering that this number excludes hydro-power.

A third answer might be found through an analysis of local actors and how they crossed and connected with regional, national and transnational networks and flows of resources. IISc in Bangalore (capital of Karnataka) is known to have developed the first prototype of their biomass gasifier by tapping into global knowledge resources through their networks. IISc built upon and adapted designs of gasifiers documented in international academic literatures. They partnered with US institutions (University of California, MITRE Cooperation) in the context of an USAID program for the reduction of oil dependency to access new flows of knowledge and financial resources (Talib, et al., 1989). Hence, an actor considered in a traditional SNM analysis as niche players (IISc), acted in and beyond the local level, circumventing the national level and directly interacting with actors across national borders, and interpreted global 'landscape' dynamics for their local interests and benefits. Moreover, it is possible that respected organizations such as IISc have had direct influence over the establishment of the National Biomass Gasification Program initiated by the Indian ministry of non-conventional energy resources in 1987. At the other end of the scale, how did IISc tap into localized networks in villages and rural areas? As pointed out by Arora and Romijn (2011), these networks themselves have cultural and power structures embedded within them. On what basis did IISc choose these locations and how did existing networks and institutions enable (or constrain) experimentation in those locations? Did the biogas niche build on already existing networks and relational assets, and how did this influence the speed and direction of innovation?

While in a traditional SNM analysis, such developments are seen as making linkages between different levels of niche, regime and landscape, it is likely that IISc was working across multiple spatial levels. In a first-generation MLP analysis, concepts of niche, regime and landscape quickly run into complex spatial multi-level realities, which would be starting points for a 3D MLP analysis.

Transnational analysis

These networks and institutions that cut across and link different geographical scales of structure and action produce complex flows of knowledge and resources. Verbong et al. (2011) come to the conclusion that national ministries have played crucial roles in the support of the biomass gasification niche in India. However, without tracing transnational networks, and the flows and resources through them, this conclusion is only weakly supported by the evidence. How did actors such as IISc, and later on the firms that commercialized the technology, mobilise resources through these networks? Such flows would need to be viewed as relational, flowing in both directions. In 2006, the largest Indian biomass gasifier producer, Ankur, had exported its systems to the UK, USA, Italy, Germany,

Russia, Sri Lanka, Australia and Cambodia.⁵ Through which transnational networks and institutions did Ankur connect with world-wide markets, and with what effects on biomass gasification niches and transition to sustainability elsewhere?

Unpacking landscape factors and processes

Finally, a 3D MLP analysis might entail studying the case from the perspective of those transnational networks and actors. How and why did existing research networks and institutions in the US in the 1980s decide to collaborate with IISc and 'choose' Bangalore as a suitable place for funding research on biomass gasification? What other transnational networks and organisations effected the development of biomass gasification in India, and with what interests? How are results from Indian biomass gasification projects mobilized by transnational networks and organisations to demonstrate their own progress in contributing to sustainable development, or in providing evidence about the effects of international assistance, or contributing to poverty reduction in India? Such questions might provide yet another perspective on how niche development occurred in India in relation with other spaces and locations abroad.

6. Summarizing conclusions

This paper has explored the foundations of a multi-scalar 3D MLP that incorporates an account of spatial scale and spatial relations between actors in explaining the evolution of socio-technical systems. We have proposed that the spatial dimension be considered as a relational scale, constituted by networks of actors across different territories. Niche, regime and landscape levels are produced and reproduced by relationships between actors acting across space and time. We therefore conceive of socio-technical change as being configured and emerging out of interactions between actors situated in structures with different temporal dynamics that are spatially heterogeneous. Locality and proximity matter, just as time and structure matter, in explaining why and how change occurs in socio-technical systems, and why it occurs in some places and not in others. We have reviewed a broad literature from economic geography and regional studies and suggested where notions from this literature can enrich the study of system innovations and transitions.

The case example in this paper has begun to show that revisiting a case from such a spatially sensitive MLP leads to new insights and interesting questions. A striking difference with the original case study would be the focus on regional differentiation within national

⁵ <http://cgpl.iisc.ernet.in/site/Portals/0/Publications/Presentations/Bio-Energy/Biomass%20Gasification%20An%20Introduction-BC%20Jain.pdf>

boundaries in combination with the role of transnational networks and institutions as important explanations. The case study has raised new insights about how local niches were connected with global resource and knowledge networks. Niche networks and actors cut across and linked different spatial levels, in the context of multiple levels of order and change and through time. These multi-scalar, multi-level processes could be further explored in future research.

Acknowledgements

This work for this paper was supported by WOTRO Science for Global Development division of the Netherlands Organisation for Scientific Research (NWO).

References

- Amin, A., 2002. Spatialities of globalisation *Environment and Planning A*. 34, 385–99.
- Amin, A., Thrift, N., 1992. Neo-Marshallian nodes in global networks. *International Journal of Urban and Regional Research*. 16, 571-587
- Amin, A. and Thrift, N., 1994. Living in the global. In: Amin, A. and Thrift, N. eds *Globalisation institutions and regional development in Europe*. Oxford University Press, Oxford: 1–22
- Archibugi, D. and Michie, J., 1997. Technological globalization and national systems of innovation: an introduction. In: Archibugi, D. and Michie, J., editors, *Technology, globalisation and economic performance*, Cambridge: Cambridge University Press, 1–23.
- Arora, S., Romijn, H., 2011. The Empty Rethoric of Poverty Reduction at the Base of the Pyramid. Organization, DOI: 10.1177/1350508411414294.
- Avelino, F., 2011. Power in Transition: Empowering Discourses on Sustainability Transitions. PhD-Thesis. Rotterdam: Erasmus University Rotterdam
- Betsill, M., Bulkeley, H., 2006. Cities and the Multi-Level Governance of Global Climate Change. *Global Governance*. 12(2), 141-159.
- Boggs, J. S. and Rantisi, N. M., 2003. The 'relational turn' in economic geography. *Journal of Economic Geography*. 3, 109–16.
- Boschma, R., Proximity and innovation: a critical assessment. *Regional Studies*. 39(1), 61-74
- Braudel, Fernand, 1982. *On History*, University of Chicago Press, Chicago.
- Brenner, N., 2001. The limits to scale? Methodological reflections on scalar structuration. *Progress in Human Geography*. 25, 591–614.
- Bulkeley, H., Castán Broto, V., Hodson, M., Marvin, S., 2011. *Cities and Low Carbon Transitions*. Routledge, New York.
- Bulkeley, H., Betsill, M., 2005. Rethinking Sustainable Cities: Multi-Level Governance and the 'Urban' Politics of Climate Change. *Environmental Politics*. 14(1), 42-63.

Bunnell, T.G., Coe, N.M., 2001. Spaces and Scales of Innovation. *Progress in Human Geography*. 25(4), 569-589

Buragohain, B., Mahanta, P., Moholkar, V.S., 2010. Biomass Gasification for Decentralized Power Generation: the Indian Perspective. *Renewable and Sustainable Energy Reviews*. 14, 73-92.

Carlsson, B., 2003. Internationalisation of innovation systems: a survey of the literature. Paper for the conference in honour of Keith Pavitt 'What do we know about innovation?'. SPRU-Science and Technology Policy Research, University of Sussex, Brighton. (http://www.sussex.ac.uk/Units/spru/events/KP_Conf_03/documents/Carlsson.pdf)

Coe, N.M., Hess, M., Yeung, H., Dicken, P., Henderson, J., 2004. Globalizing regional development: a global production networks perspective. *Transactions of the Institute of British Geographers*. 29(4), 468-484

Coenen, L., Benneworth, P., Truffer, B., 2012. Towards a Spatial Perspective on Sustainability Transitions. *Research Policy*. 41, 968-979

Coenen, L., Raven, R.P.J.M., Verbong, G.P.J., 2010. Local niche experimentation in energy transitions: a theoretical and empirical exploration of proximity advantages and disadvantages. *Technology in Society*. 32, 295-302

Cox, K., 1998. Spaces of dependence, spaces of engagement and the politics of scale, or: looking for local politics. *Political Geography*. 17, 1–23.

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

Ernst, D., Kim, L. 2002. Global production networks, knowledge diffusion and local capability formation. *Research Policy*. 31, 1417–1429.

Garud, R., Karnoe, P., 2003. Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship. *Research Policy*. 32, 277-300.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*. 31, 1257-74.

Geels, F.W., 2011. The multi-level perspective on sustainability transitions: responses to seven criticisms. *Environmental innovation and societal transitions*, 1, 24-40.

Geels, F.W., Raven, R.P.J.M., 2006. Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973-2003). *Technology Analysis & Strategic Management*. 3/4, 375-391.

Geels, F.W., Raven, R.P.J.M., 2007. Socio-cognitive evolution and co-evolution in competing technical trajectories: biogas development in Denmark (1970-2002). *International Journal of Sustainable Development & World Ecology*. 14, 63-77.

Geels, F.W., Schot, J.W., 2007. Typology of Socio-Technical Transition Pathways. *Research Policy*. 36, 399-417.

Gibson, C.C., Ostrom, E., Ahn, T.K., 2000. The concept of scale and the human dimensions of global change: a survey. *Ecological Economics*. 32, 217-239

Giddens, A., 1984. *The Constitution of Society. Outline of the Theory of Structuration*. Cambridge: Polity.

Grin, J., Rotmans, J., Schot, J.W., 2010. *Transitions to sustainable development. New directions in the study of long term transformative change*. Routledge, New York.

Haas, P.M., 1990. *Saving the Mediterranean: The Politics of International Environmental Cooperation*. Columbia University Press, New York.

Henderson, J., Dicken, P., Hess, M., Coe, N., Yeung, H., 2002. Global production networks and the analysis of economic development. *Review of International Political Economy*. 9(3), 436-464

Hess, M., 2004. 'Spatial' relationships? Towards a reconceptualization of embeddedness. *Progress in Human Geography*. 28, 165-86.

Hillman, K.M., Suurs, R., Hekkert, M.P., Sandén, B., 2008. Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden. *Technological Analysis & Strategic Management*. 20(5), 593-612.

Hodson, M., Marvin, S., 2009. Cities mediating technological transitions: understanding visions, intermediation and consequences. *Technology Analysis and Strategic Management*. 21 (4), 515–534.

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

Howells, J., 1990. The internationalization of R&D and the development of global research networks. *Regional Studies*. 24, 495–512.

Hyysalo, S., 2010. *Health Technology Development and Use. From Practice-Bound Imagination to Evolving Impacts*. Routledge, New York.

Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation. Explaining the German diffusion of renewable energy technology. *Energy Policy*. 34, 256-276.

Jorgensen, U., 2012. Mapping and Navigating Transitions. The Multi-Level Approach Compared with Arenas of Development. *Research Policy*. 41, 996-1010

Kamp, L.M., Smits, R.E.H.M., Andriessen, C.D., 2004. Notions on learning applied to wind turbine development in the Netherlands and Denmark. *Energy Policy*. 32, 1625-1637.

Keck, M.E., Sikkink, K., 1998. *Activists Beyond Borders: Advocacy Networks in International Politics*. Cornell University Press, Ithaca.

Kern, F., Smits, A., 2008. Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy Policy*. 36, 4093-4103.

Latour, B., 2005. *Reassembling the Social. An Introduction to Actor-Network-Theory*. Oxford University Press, Oxford.

Lawhon, M., Murphy, J.T., 2012. Socio-technical regimes and sustainability transitions: insights from political ecology. *Progress in Human Geography*. 36(3), 354-378

Lewis, J. I., 2007. Technology Acquisition and Innovation in the Developing World: Wind Turbine Development in China and India. *Studies in Comparative International Development*. 42(3-4), 208-232.

Loorbach, D., 2007. Transition Management: new mode of governance for sustainable development. PhD thesis, Erasmus University Rotterdam.

Markard, J., Raven, R.P.J.M., Truffer, B., 2012. Sustainability Transitions. An Emerging Field of Research and its Prospects. *Research Policy*. 41, 955-967.

Massey, D., 1984. *Spatial divisions of labour*. MacMillan, London.

Massey, D., 2004. Geographies of responsibility. *Geografiska Annaler: Series B, Human Geography*. 86(1), 5–18.

Meadowcroft, J., 2009. What about the politics? Sustainable development, transition management, and long term energy transitions. *Policy Sciences*. 42, 323-340.

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

Müller, Michael G., and Cornelius Torp, 2009. Conceptualising Transnational Spaces in History. *European Review of History: Revue européenne d'histoire*. 16 (5), 609-617.

Negro, S.O., Suurs, R.A.A., Hekkert, M.P., 2008. The bumpy road of biomass gasification in the Netherlands: Explaining the rise and fall of an emerging innovation system. *Technological Forecasting and Social Change*. 75(1), 57-77.

Pavitt, K. and P. Patel (1999). Global Corporations and National Systems of Innovation: Who Dominates Whom? In: D. Archibugi, J. Howells and J. Michie., editors. *Innovation Policy in a Global Economy*. Cambridge: Cambridge University Press. 94-119.

Porter, M.E., 1990. *The competitive advantage of nations*. London: Macmillan.

Rip, A., Kemp, R., 1998. Technological change, in: Rayner, S., Malone, E.L. (Eds.), *Human choice and climate change*, Vol. 2. Batelle Press, Columbus, 327-399.

Schot, J., 1998, The usefulness of evolutionary models for explaining innovations. The case of the Netherlands in the nineteenth century. *History of Technology*. 14, 173-200.

Saunier, Pierre-Yves, 2008, Learning by doing. Notes about the Making of the Palgrave Dictionary of Transnational History. 6 (2), 159-180.

Sheppard, E., 2002. The spaces and times of globalization: place, scale, networks, and positionality. *Economic Geography*. 78, 307-30.

Shove, E., Walker, G., 2007. CAUTION! Transitions ahead: politics, practice and sustainable transition management. *Environment and Planning A*. 39, 763-770

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

Smith, A., Vosz, J., Grin, J., 2010. Innovation studies and sustainability transitions: the allure of the multi-level perspective. *Research Policy*. 39, 435-448.

Storper, M., 1997. *The regional world*. Guilford: New York.

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

Talib, A., Goss, J.R., Flanigan, V.J., Grover, P.D., Mathur, H.B., Durgaprasad, M.B., 1989. Development and Field Testing of Small Biomass Gasifier-Engine Systems in India: A Joint Project by an American and Indian Team. *Biomass*. 19, 99-122.

Truffer, B., Coenen, L., 2012. Environmental innovation and sustainability transitions in regional studies. *Regional Studies*. 46(1), 1-21

Verbong, G.P.J., Christiaens, W., Raven, R.P.J.M., Balkema, A., 2010. Strategic Niche Management in an Unstable Regime. Biomass Gasification in India. *Environmental Science and Policy*. 13, 272-291.

Vleuten, E. van der. Towards a Transnational History of Technology. Meanings, Promises. Pitfalls. *Technology and Culture*. 49(4), 974-994.

Vleuten, E. van der, Høgselius, P., forthcoming. Resisting Change. The transnational dynamics of European energy regimes, in: Verbong, G.P.J., Loorbach, D. (Eds.), *Governing the Energy Transition. Reality, Illusion or Necessity*. Routledge.

Yeung, H.W., 2005. Rethinking relational economic geography. *Trans Inst Br Geogr.* 30, 37-51.