Review

Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges

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ABSTRACT

Sustainable development is prompting a re-assessment of innovation and technological change. This review paper contributes three things towards this re-assessment activity. First, it considers how the history of innovation studies for sustainable development can be explained as a process of linking broader analytical frameworks to successively larger problem framings. Second it introduces an emerging framework whose allure rests in its ability to capture the bigger picture: the multi-level perspective on socio-technical transitions (MLP). Whilst burgeoning researcher networks and literature suggests this policy-relevant theory is attractive, it is not without its challenges. The third purpose of this paper is to elaborate these challenges as areas for further research and development. We do this by drawing upon contributions to this special section and the wider literature.

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1. Introduction

The promise of greener innovation has long featured in debates about mitigating environmental degradation under industrial development. Emphasis in innovative capabilities lay at the heart of critical responses to the Malthusian *Limits to Growth* report by the Club of Rome in the 1970s (Meadows, 1972). Critics argued that the Club's modelling underplayed the possibility for innovation to stretch and redefine 'limits', and thereby avoid environmental and social collapse (Cole et al., 1973; Freeman, 1979). More recently, ideas about ecological modernisation consider how innovation can redirect production towards environmental goals, and decouple economic growth from environmental degradation (Jänicke, 1985, 1988; Huber, 1982, 1993; Spaargaren and Mol, 1992; Vergragt and Jansen, 1993; Hajer, 1995).

Innovation studies has much to offer those interested in ensuring new products, processes and services improve human wellbeing without detriment to environmental life support systems. Innovation studies can explain how and why such "greener" production and consumption practices come about, or do not, and suggest how these kinds of practice might be accelerated at the expense of environmentally more harmful alternatives. We note that concern for sustainable development tends to demand a broadening of perspective in innovation studies. The first purpose of this paper is to explain the logic for this broadening of perspective. It works on two dimensions.

The first dimension is a *broadening of the problem framing*. This comprises definition of the purpose and outcomes of innovative activity and, linked to this, delineation of the focal object of innovation studies, i.e. the "thing" that undergoes innovation. Thus we explain a broadening from a focus on the promotion of cleaner technologies in the 1980s and towards current interest in innovating entire systems of production and consumption. The second dimension is a *broadening of the analytical framing*: the set of considerations used to explain the emergence and success of innovation. This starts from a neo-classical environmental economics understanding of price signals inducing innovation and leads into a variety of innovation systems perspectives.

We argue that developments in both dimensions, problem framing and analytical approach, have done a lot to increase the significance of innovation studies for sustainable development. Nevertheless, a further step is under way. A broad, multi-level perspective on socio-technical transitions (MLP) claims to be able to analyse the broader problem framing of innovating entire systems of production and consumption. The introduction and critical assessment of the MLP is the second purpose of this paper.

The MLP developed out of explanations for historic transitions to new socio-technical systems for mobility, sanitation, entertainment, food, lighting and so on. Successful systems are constituted from networks of artefacts, actors, and institutions and gain stability and path-dependence as particular 'socio-technical regimes' (e.g. the regime of centralised power generation on the basis of fossil and nuclear fuels). The conceptual understanding of transitions to new regimes draws upon theories at the interface of innovation studies and STS. They combine a view on the micro-level processes of constructing new technologies, with a view on emerging macro- and meso-level patterns of culture, organisation, markets, regulation and infrastructures (Rip and Kemp, 1998; Schot, 1998; Geels, 2002).

The allure of the MLP for sustainability research rests in this engagement with the dynamics of large-scale socio-technical systems deemed to present persistent sustainability challenges (Rotmans et al., 2001; Berkhout, 2000; Elzen et al., 2004). However, this attractive big picture is not without its challenges. A third and final purpose for our paper is to draw on contributions to this special section in order to discuss some of the challenges[1]: conceptual challenges in terms of defining the unit of analysis; analytical challenges in addressing structural power, agency, and geography; and practical challenges in appraising the governability of socio-technical transitions. We conclude by suggesting what this means for future research agendas in this area.

The contributions to this special section force reflection on normative orientations in innovation processes and the social and political aspects of knowledge production and technology development. This may inspire further development of innovation studies, connecting innovation theory with science and technology studies (STS). As Frank Geels' contribution points out, explicit concern for normative directions can further open innovation studies to theoretical and ontological traditions that have hitherto remained marginal. A recent review of STI called for precisely that kind of broader dialogue between approaches, as well as being more reflexive in the analysis of innovation (Morlacchi and Martin, 2009). The contributions in this special section are in that spirit, and suggest the MLP provides a promising heuristic for organising such a dialogue. Our intent is not to present the MLP as a finished product, but to introduce it in a critical and reflexive way that invites others in innovation studies to contribute to its future development. Whilst the future research agenda we identify includes issues pertinent to the MLP as an analytical framework, we also flag up issues that relate to the practical challenge of governing sustainable transitions in general.

In following the aims for this paper we cover considerable ground. The next section explains the broadening of problem framings and analytical approaches. Section 3 then introduces the MLP. The state of the art for the MLP shows its breadth and work in progress quality and gives a background to its use as a flexible heuristic. This is reflected in the diversity of the contributing papers. Section 4 summarises main points from these contributions, before Section 5 discusses the challenges they raise for the MLP and sustainability transitions. Section 6 concludes with suggestions for a future research agenda.

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2. The logic of adopting a broader perspective in sustainable innovation

Sustainable development emphasises *explicit* interest in the normative direction of innovation. The challenge for innovation no longer rests solely in economic potential, but also in the societal changes induced by innovative activity and the consequences of this for environmental and social sustainability. Along with this broader problem framing, comes a need for broader analytical perspectives.

Innovation system analysis is an approach that has been helpful in explaining the level of innovative activity: the quantitative output from economies, sectors or regions in terms of new patents, products or technologies. Adapted to particular technologies it has also helped to understand the success and failure of certain innovations and related economic sectors in different economies. This builds on an analytical framing which includes public policies, institutional settings, inter-organisational networking, learning processes and knowledge infrastructures, and entrepreneurial capabilities. Innovation systems can help us understand how the flow of greener goods and services might be accelerated, but appears not so clear in understanding how these rely upon and induce broader structural changes for sustainable development.

The challenge of sustainable development demands policies to promote a change in what Hughes (1987, pp. 15–16) has called the momentum of socio-technical systems. This comprises mass (the objects, actors and infrastructures involved), speed (the pace at which socio-technical developments and their alignment develops), and direction (the overall performance of the system changes as a result of innovations). The direction of momentum is probaly the most challenging one, helping innovative activity move onto a path where desired outcomes can be expected, and deflecting it from less desirable trajectories.[2]

Directionality is not only challenging for reasons of the uncertain systemic effects of innovations. It is also challenged by ambivalence over standard measures of 'sustainability'. The precise meanings and trade-offs for society between specific environmental, social and economic features of innovative activities are open to interpretation and negotiation. Sociological sensitivity towards inter-subjective meanings of sustainable innovation, and the role of political and economic power in privileging certain perspectives over others, becomes important. Sustainable development may thus be seen as broadening innovation studies to include reflexivity issues more typical in STS, but turned towards innovation studies concerns for the large-scale creation of novelty, industry structure and evolutionary change over the longer-term.

2.1. An initial broadening in problem framing: from clean technology to industrial ecology

A theme prevalent in research and policy in the literature in the early 1990s was interest in promoting innovation for environmentally friendly technology. A switch in focus from early preoccupation with end-of-pipe pollution control technologies and towards cleaner production processes and product innovation represented an initial broadening in problem framing. The new cleaner technology paradigm was concerned with innovations integral to

processes and products, reducing contamination, waste and material use at source. Some argued the associated material savings translated into reduced costs, and hence greater business competitiveness (Ashford et al., 1985; Porter and van der Linde, 1995; Howes et al., 1997; Rennings, 2000). Other studies foresaw new environmental industries and new markets and jobs as the economy undergoes an ecological modernisation (Jänicke, 1988). This remains a topic of considerable debate (York and Rosa, 2003). Nevertheless, a dynamic and innovation-oriented consideration of potential benefits for business provides a more positive outlook and constructive ground for dialogue compared to static economy-versus-environment debates.

Throughout the 1990s, some trade associations and firms began innovating environmental management systems as a way of demonstrating improving environmental performance to increasingly attentive stakeholders (Welford, 1995).[3] The challenge was to ensure that these environmental management approaches moved from being a peripheral site-management exercise to become an influence upon core business strategies and innovation agendas across sectors (i.e. from concern for emissions from production processes to concern for the life cycle environmental performance of the goods and services produced). A literature in industrial ecology broadened the problem framing further by considering how either entire sectors or industrial parks might close loops and make material flows more sustainable (e.g. Ayres and Simmonis, 1994). The environmental innovation problem framing was broadening, in the sense that it included organisational innovations across sectors and the development of greener goods and services across the lifecycle, and not just cleaner technology at the firm level.

2.2. Broadening the analytical perspective: from environmental economics to evolutionary perspectives on environmental innovation

Innovation studies rooted in evolutionary economics provide a helpful corrective to (neo-classical) environmental economics perspectives. The latter see the challenge of environmental innovation as resting predominantly in adjusting price signals for goods and services. Environmental considerations are poorly served by existing markets, so the environmental economists argue, because costs and prices fail to internalise environmental externalities, and consequently fail to generate effective demand for cleaner innovations (Pearce et al., 1989). Market-based environmental policy measures (e.g. eco-taxes and tradable quotas) can internalise the social costs of environmental degradation (i.e. market externalities), and thereby provide a more balanced price incentive for innovating goods and services.[4]

Reliance on this 'demand-pull' approach has its shortcomings. It brackets out many of the reasons why responses to environmental price signals are sticky and inelastic. Taxes have to correct price signals to a politically difficult level for long periods before less resource consuming innovations relieve the pressure. Case studies and survey research identified overlapping cognitive, social,

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[2] The innovations systems perspective did develop out of consideration for how innovation explained the contrasting structures and dynamics of national economies. This can involve normative interest in the different directions of economic development and the distribution of standard measures of prosperity. Here we mean directionality in a more multivalent and contested normative concern for sustainable development. Sustainability is not unique in rendering more visible normative contests over innovation directions.

[3] Often regulatory push was found to induce greener innovation (Ashford et al., 1985; Howes et al., 1997). Significantly, it was the way these regulations were implemented that mattered, and the extent to which regulators were able to act as knowledge brokers between firms adapting innovative ideas, technologies and practices (Smith, 1996; Gouldson and Murphy, 1998).

[4] Neo-classical environmental economists found a receptive policy audience amongst the New Right for their market-based ideas. The environmental regulations of the 1970s became ideologically tarred as too restrictive and burdensome on business. Environmental taxes and tradable quotas were the preferred, market-friendly approach (rhetorically at least) to inducing cleaner innovation in firms. In practice, regulations can be flexible and retain advantages that ensure their continued importance within environmental policy mixes (Smith and Sorrell, 2001).
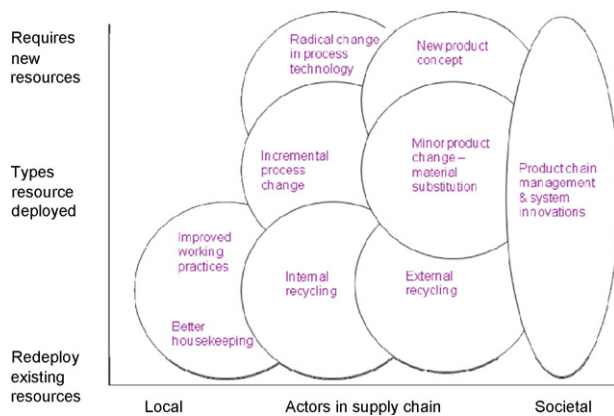
Fig. 1. Knowledge capabilities and actor networks in sustainable innovation (adapted from Clayton et al., 1999).

institutional and political barriers, in addition to narrow market barriers, as critical for greener innovation (Fischer and Schot, 1993; Howes et al., 1997; Kemp, 1994a,b). A wider analytical perspective needed to include these non-market considerations in its analysis.

As an illustration, Clayton et al. (1999) considered the different knowledge capabilities and extensiveness of actor networks associated with a variety of cleaner innovation cases (Fig. 1). This mapping can be extended to consider the distribution of other resources required for each type of environmental improvement in their scheme, such as equipment, skills, finance, supportive infrastructures, and institutional support.

As with an earlier generation of critical studies on the understanding of innovation dynamics in neo-classical economics (e.g. Dosi, 1982; Nelson and Winter, 1982; Dosi, 1988), the cleaner innovation literature found price signals to be necessary, yet insufficient to assure innovative responses on the supply-side of the market. Evolutionary perspectives offered a more nuanced way of considering the greening of production processes by bringing the factors into view that shape innovative activity on the supply-side (Green et al., 1994). This analytical broadening did not simply consider R&D subsidies as a complement to eco-taxes. Other institutional factors were important for the innovation of cleaner production processes, including search routines, knowledge capabilities, prevailing technology paradigms and regimes (Kemp, 1994a,b).

2.3. A further broadening in analytical perspective: greener innovation systems

Firm-level studies of environmentally oriented innovation processes continue to be an important activity, as well as supporting a large consultancy sector. This is where much of the hard slog towards a shift in industry structures needs to take place. It is an area of policy and business activity, however, that can benefit considerably from the analysis of broader innovation systems in which firm-level activities are embedded (Freeman, 1992). This refers to institutional frameworks influenced by policy-makers and broader governance processes, the system of innovation, as it were. Much depends on e.g. provision of workers with the requisite skills, the integration of cleaner technologies in network infrastructures, safety standards, planning procedures and other market rules which have an effect for facilitating or hampering environmental innovations. The innovation studies literature suggests environmentally oriented innovation policy must take a broader systems perspective, recognising institutions operating beyond the firm and networks of different organisations such as firms, universities, financial service providers.

Recognising that the capabilities of individual organisations to innovate, as well as their broader selection environments, are constituted by more complex processes opens analysis to related practitioner routines, skills and training, governing institutions, facilitating infrastructures, and effective and prospective market demand. This is an insight which is at the root of the systems perspective in innovation studies and various strands of research focusing on the structure and performance of national, sectoral, regional or technological innovation systems (Lundvall, 1992; Breschi and Malerba, 1997; Truffer, 2008). Central to this innovation systems perspective is how this work is distributed across the research, government and business sectors.

The greener innovation systems perspective adapts innovation system analysis by adding an interest in how the functioning of the innovation system becomes subordinate to the sustainability qualities of its outputs (Green et al., 1994). Recent work on technological innovation systems (TIS), for instance, developed with a concern for the success of innovations that are expected to be particularly favourable from an environmental point of view (e.g. renewable energy technologies). Extensive literature review provided a framework for explaining the success of innovative technologies which can also be used to strategically guide the development of desired technological innovation systems (Jacobsson and Bergek, 2004). A functions approach is deployed to identify those properties of a technology innovation system that are needed in order to introduce cleaner technologies successfully. These functions include: experimentation by entrepreneurs; knowledge development and diffusion; providing orientation to search processes; creating markets; mobilising resources; and securing policy legitimacy (Hekkert et al., 2007).

As with earlier innovation system formulations, interest in wider institutional, historical, material, cultural and geographical contexts takes the form of a set of (exogenous) structural parameters that contribute to explanations of innovative success (or failure) of a core innovation system (Bell, 2007). The core system is comprised of networks of firm capabilities, knowledge infrastructures and proximate policy and market institutions. Innovation systems analysis covers this core well (Edquist, 2005). As the TIS literature points out, *some* of the difficulties in establishing greener innovation systems can be explained by the absence of certain core functions or because the system is unable to align functions. However, it remains unclear where these absent functional capabilities come from, or how they develop. We do not learn much in the TIS literature about difficult governance questions such as how to identify 'sustainable' technologies and how to prioritise them. Much of that explanation rests in the broader societal contexts in which specific innovation systems operate, and which tend not to be considered in dynamic interaction with the core (Markard and Truffer, 2008; Bell, 2007).

So whilst innovation systems analysis can help explain the relative success of specific cleaner technologies, analysis is often in a situation of needing to explain the difficulties of making such "green" innovation systems come about. Analysis needs to focus on the way broader contexts put pressure on innovation systems to become greener and inform their reconfiguration.

The preceding remarks have a crucial implication. Reconfigured and reprioritised innovation systems may contribute to sustainable development through provision of greener goods and services. But the possibility to do this reconfiguring will be structured (in both enabling and constraining ways) by wider contexts that frame, motivate and interpret innovation system activities, and which may actually attenuate the benefits of individual cleaner innovations. This broader analytical perspective is recognised in the innovation systems literature, as is a concern to explain the directionality of the technological trajectories that ensue (Bell, 2007; Nelson, 2008; Von Tunzelmann et al., 2008).

2.4. A further broadening in problem framing: system innovation for sustainability

It is the broadening of problem framing to a perspective on 'systems innovation' that poses an additional challenge to the analytical framing of innovation systems. Systems innovation refers to the renewal of a whole set of networked supply chains, patterns of use and consumption, infrastructures, regulations, etc., that constitute the socio-technical systems which provide basic services such as energy, food, mobility or housing. This broadening of problem framing goes beyond isolated products, processes or technologies. It acknowledges difficulty in evaluating the sustainability of isolated technologies, if not analysed as embedded in a system context.[5] And it acknowledges strong interdependencies between various elements of socio-technical systems which impede radically new ways of organising socio-technical provision (e.g. renewable energy, organic agriculture, public transport or ecological building).

Until recently the focus of environmentally oriented innovation studies has remained largely upon innovations to individual goods and services. A greener innovation system may produce more eco-efficient products or services, or even enable industry clusters to develop more closed-loop processes. But the relative improvements they deliver can be undermined by absolute increases in consumption. A need for step-jumps in absolute performance, such as 80% reductions in carbon emissions over the next generation, or factor ten improvements in resource efficiency, implies changes at the level of entire socio-technical systems. These system innovations, such as transformative innovations that overhaul food systems or waste systems, involve purposeful changes in prevailing techno-economic paradigms and system architectures (to use the Freeman-Perez typology of innovation). As such, systems innovation takes an even broader view than earlier perspectives on innovation and sustainable development; making it far more ambitious and posing even greater analytical and governance challenges.

As Weber and Hemmelskamp (2005, p. 1) put it, sustainable systems innovation implies:

> major changes are required along the entire production-consumption chain, its flows, its multi-level architecture, its institutions and structures, and – not least – the behaviour of the actors involved in it, from resource extraction to the final consumption of goods and services.

The challenge of sustainable development is increasingly understood in terms of 'transitions' to more sustainable socio-technical systems. The 2002 World Summit on Sustainable Development in Johannesburg initiated cross-cutting programmes for transforming sustainable production and consumption systems (the UN Marrakech process). The UK government announced a Low Carbon Transition Plan for its economy in 2009, joining the Netherlands, Austria, Belgium and Finland with 'transition' ambitions (Geels et al., 2008). Governments, businesses and civil society groups are considering what reformed innovation policy looks like through this sustainable socio-technical transitions framing.

Hoogma et al. (2002, p. 5) argue:

> 'Ecological restructuring of production and consumption patterns will require not so much a substitution of old technologies by new ones, but radical shifts in technological systems or tech-

nological regimes including a change in consumption patterns, user preferences, regulations, and artefacts'

This poses a challenging advance on research rooted in more specific environmental innovation studies of the types mentioned above (Tukker et al., 2008). Relative to innovations in Fig. 1, 'systems innovation' sits well beyond the top right of that scheme.

Studying food systems, for instance, means technical elements—physical inputs, plant-breeding techniques, pesticides, harvesting technologies, transport and logistics, food processing, cooking technology, and so on—are studied in tight relation to the social elements giving these artifacts meaning and purpose—such as prevailing attitudes towards farming, ideas about soil health and nutritional food, official agricultural policy and price-support mechanisms, organised interests, the structure of food retailing, shifting trends in food consumption, and other social considerations, including concern about long-term environmental sustainability (Smith, 2006). It is the co-evolution of these social and technical elements that determines the way the food system is structured and how it performs (Russell and Williams, 2002). The analytical challenge is to understand these socio-technical interdependencies as a dynamic system, and then identify how systems innovation can induce a transition to other, potentially more sustainable, systems.

So, the key difference between the greener innovation systems literature and systems innovation (socio-technical transition) literature is the starting points and focal objectives of each. The innovation systems problem framing is (predominantly) concerned with the promotion and introduction of greener goods and services into markets. The systems innovation literature frames its problem as concern for the realisation of 'societal functions' through the configuration and alignment of heterogeneous socio-technical elements and processes, and how these restructure over long periods of time. Markets are an important part of this broader picture, but so too are other institutions.

2.5. Another broadening in analytical perspective: transitions in socio-technical regimes

The challenge then, is to find an analytical perspective on innovation that is commensurate with the extended problem framing of system innovations for sustainability: how can we understand innovation processes leading to transformations in socio-technical systems that help realise broad social functions more sustainably? Two related strands of research help, which are: historically informed theory for wide-scale changes to technology-in-society; and, problem-oriented thinking for sustainable transitions.

The *first strand* provides a 'quasi-evolutionary' conceptualisation of historic transitions in societal functions. It combines sociological appreciation of processes of technology shaping, as in SCOT, with more structural notions of 'technological regimes' and 'paradigms' prevalent in evolutionary economics (Rip, 1995, see Geels' paper in this special section). Research emphasises the ways selection environments are anticipated, reinterpreted and (partially) transformed by (networked) innovators (Rip, 1992; van den Belt and Rip, 1987; Disco and van der Meulen, 1998). Relevant studies are those interested in how new technologies become involved in wide-ranging processes of social change (e.g. the move from gas light to electric light (Schot, 1998), from sail to steam ships (Geels, 2002), the rise of the turbo-jet in aviation (Geels, 2006), improvements in public sanitation (Geels, 2006b). This strand of research is not interested in normative goals like sustainability.

This historic work extends technological paradigm and regime concepts, and re-conceives how they shape trajectories of development. Earlier work was more interested in the way regimes operated (Dosi et al., 1988; Nelson and Winter, 1982), and less

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[5] Special section contributions illustrate an important aspect to transitions, which is the way the 'societal function' is itself altered through transitions between regimes. Expectations about mobility have, for instance, altered with developments in the socio-technical systems that move us around (see Shove and Walker, and Cohen, both in this issue); as have adequate levels of energy service with the development of energy systems (see Spaeth and Rohracher in this issue).

focused in how they related to social institutions beyond markets and science (e.g. Dosi, 1982; see also Nelson, 2008). As an otherwise positive review of that literature concluded, 'how to catch [paradigms] as they form, and manage the formation and establishment of new ones, remain very poorly understood and under researched' (Von Tunzelmann et al., 2008, p. 482). As we shall see in the next Section, transitions between regimes are central to the MLP.

A socio-technical perspective reconceptualises regimes beyond the core cognitive structures emphasised by Dosi and others (Geels, 2004).[6] A sociological sensibility extends the regime notion to embrace institutions (such as regulations and markets), heterogeneous networks (including devices and people), user relations, and social expectations. Mutual reinforcement across these plural processes creates the structural patterns that shape innovation and creates trajectories of social development. The regime of automobility, for example, includes not only paradigmatic technological designs for cars, but also the specialised road planning authorities, the institutions of the 'driving licence' and 'motor insurance', the lobbying capacities of car manufacturers and oil companies, and the cultural significance of automobility. In combination, these elements form a socio-technical regime that stabilises the way societal functions are realised, and gives shape to particular patterns of producing and consuming mobility.

Transitions in regime structures are consequently seen to arise through an accumulation of a broader variety of interacting processes than the knowledge base and markets alone. 'How technology is shaped by social, economic and political forces alike, and how, in the same process, technologies and technology systems shape human relations and societies' (Rip and Kemp, 1998, p. 328). So, for example, the transition from a 'society with candle and gaslight' to a 'society with electrical light', emphasises some of the social, political and economic factors facilitating this transition, as well as the developmental possibilities opened up by the emergence of new regimes, and the meanings associated with those developments (Schot, 1998). Transition scholars are interested in the broader societal transformations arising from the establishment of novel technological regimes, but also how broader societal developments are effectively selecting between possible would-be regimes and exerting pressure on them to adapt or causing them to wither.

Such interests resonate with the concerns of sustainability researchers, where interest centres upon challenges like transiting away from fossil-fuelled energy systems and towards low carbon alternatives (Kemp, 1994a,b; Rip and Kemp, 1998; Smith et al., 2005). Thus the *second strand* of research, involving researchers working in the historical strand, but also in the Constructive Technology Assessment tradition, is explicitly concerned with broader, regime approaches to sustainable innovation (Rip and Kemp, 1998; cf. Kemp, 1994a,b; Rip et al., 1995). Scholars in this second strand discuss the prospective conditions under which sustainable transitions in transport, energy, housing and so on might develop (e.g. Elzen et al., 2004).

Thinking prospectively, many sustainability goals imply transitions over much tighter time-frames than the historic examples that inspire systems innovation analysis (e.g. Rotmans et al., 2001; Loorbach, 2007; see the special issue on transition management in issue 4, volume 42 of *Policy Sciences* in December 2009). These goals include ambitions to reduce anthropogenic carbon emissions by 80% or more within 40 years, or the 2015 target date for Millennium

Development Goals that include reducing by half the proportion of people without sustainable access to safe drinking water and basic sanitation. Some transitions, like the move from coal heating to gas heating in parts of north-western Europe, have proceeded rapidly (Correljé and Verbong, 2004). Many others arose over five or more decades. The prospect for sustainability need not be as bleak as the historic timescales suggest. Arguably, there has been a slow build up of ideas, experience and green niches over the last 40 years, going back to the alternative technology movement and public research programmes of the 1970s (Smith, 2005, 2007). Nevertheless, public sustainability aspirations imply a rapid acceleration in these activities and any systems innovations they may induce.

Sustainability transitions research is engaged in aiding political deliberations and governance activities that can accelerate the take off of some of these green niches, and bring about restructured production and consumption systems. Researchers in the Netherlands especially have helped reshape environmental policy along transitions lines (Kemp et al., 2007; Smith and Kern, 2009). Researchers in other countries have also been commissioned by think tanks and policy departments to explore the potential of systems innovation approaches (Steward, 2008; Scrase et al., 2009). The multi-level perspective on socio-technical transitions (MLP) provides them with an alluring framework, both in terms of organising analysis and ordering policy interventions. It is this framework this special section considers, and which we introduce in the next section.

3. The multi-level perspective for analysing sustainable transitions

The multi-level perspective organises analysis into a socio-technical system that consists of niches, regimes and landscapes. This is a nested hierarchy of structuring processes (Geels and Schot, 2007), analogous to Giddens' (1984) concepts of reflexive agency and structure. Socio-technical regimes constitute the mainstream, and highly institutionalised, way of currently realising societal functions. Change within the regime tends to be incremental and path dependent. Regimes also exert a structuring force upon novel alternatives, which arise in niche spaces. In a Kuhnian vein, regimes tend to produce 'normal' innovation patterns, whilst 'revolutionary' change originates in 'niches'. The implication is that the quality of incremental innovations subsequently generated within a new regime will be radically different to those under the preceding regime. Finally, both niches and regimes are situated within a broader landscape of social and physical factors that provides a macro-level structuring context. Over time, the rise of some regimes can prove quite influential upon broader landscape developments. An example is the catalytic effect aeromobility and communications regimes have upon socio-economic globalisation (and which reinforces the continued development of these regimes) (see Cohen, this issue).

3.1. Socio-technical niches

In the MLP, transitions are crucially dependent upon activities within niches, where selection pressures prevailing in regimes are less evident. Niches provide 'protective spaces' for path-breaking, radical alternatives whose performance may not be competitive against the selection environment prevailing in the regime (Rip, 1992, p. 91; Kemp et al., 1998). Niche protection can be afforded through lead markets, subsidised projects for research demonstration and learning, or specific cultural milieu of early adoption and experimentation. Niches that provided seeds for transitions historically had to overcome the constraining influence of regimes, branch out, link up with wider change processes, and drive trans-

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[6] Dosi adapted his technology paradigm concept from Kuhn's ideas about scientific paradigms. Perhaps this explains why Dosi's definition of technology emphasises the knowledge embodied in technological practice cf. the materiality of technology devices?

formations in those same regime structures over the longer-term. Many niches are not successful in expanding, or even surviving for a long time.

Sustainable niches comprise networks of real world experiments with socially and ecologically benign socio-technical practices The actors (producers and users) undertaking these experiments are relatively more supportive of the social and environmental qualities of the niche socio-technical practice, and more forgiving of teething troubles, owing to their different expectations of future performance compared to regime members. The norms in the niche are different compared to the rules in the regime but tend also to be less established and relatively instable. Whilst 'outsiders' can be important instigators of niche developments, such as environmental activists in the early development of modern wind energy, actors established within the regime must become involved in those activities for wide-scale influence, such as large energy utilities in wind. Niche success ultimately rests upon broader circles of more powerful actors becoming involved in ways that mobilise widespread social legitimacy (Schot, 1998; Späth and Rohracher, this issue).

Niche development is predicated upon valuable lessons being generated, supportive institutional requirements becoming better articulated, and enrolling commitments from a growing network of actors (including potential investors and users from more mainstream settings) (Raven, 2006). Niche actors need to perform considerable cognitive, institutional, economic and political work: they have to be persuasive to a variety of constituencies on different terms (Smith, 2007; Hendriks and Grin, 2007). In these ways niches compete with the incumbent regimes, outperform them and take over. The expectations motivating the niche pioneers have to align with expectations prevalent in the regime (Schot, 1998; Smith, 2007). As such, niches are a source for transformative ideas and capabilities, but not blueprints. Their potential is constrained, enabled and interpreted through the more powerful structures of the regime (Roep et al., 2003; Grin et al., 2004; Bos and Grin, 2008).

3.2. Socio-technical regimes

Socio-technical configurations in regimes are established as the stable and dominant way of realising a particular societal function. Socio-technical regimes are structures constituted from a co-evolutionary accumulation and alignment of knowledge, investments, objects, infrastructures, values and norms that span the production-consumption divide.[7] These heterogeneous configurations are the prevailing means for realising key societal functions. Institutional and material interdependencies constituting the regime mean realignments tend to be path dependent and incremental. It is this dynamic structure which sustainable niches must overcome if they are to unsettle the regime and seed a transition.

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[7] There are ambiguities in the definition of regime in the literature. Geels (2002), whilst not yet shifting terminology from 'technological regimes' (as in evolutionary economic theories) to 'socio-technical regimes', nevertheless takes a broader analytical view: guiding principles, technologies and infrastructures, industrial structure, user relations and markets, policy and regulations, the knowledge base of the regime, and culture (the symbolic meanings underpinning the material practices in the regime). Later, Geels (2004) considers regimes on more institutional terms, as the 'rule set' that guides the development of material socio-technical systems—a depiction that is actually closer to (evolutionary economic) innovation theory. In a thoughtful review, Markard and Truffer (2008) note this tension between institutional understandings of the regime, and more material understandings that include the actors and artefacts whose practices develop the rule set (e.g. Verbong and Geels, 2007). It is difficult to conceive a pattern of socio-technical practices reproducing without the presence of institutions, just as it is difficult to see how institutions can persist without their re-enactment through networks of actors engaged in material practices (Smith et al., 2005).

Dynamics within the regime derive from partially autonomous developments within regime components, such as firm R&D, or government regulations, which generate misalignments and realignments and incremental responses. Dynamism may also occur in response to landscape developments (see below), or through interaction with associated regimes (Raven and Verbong, 2007; Konrad et al., 2008). These sources of dynamism, and the tensions they create, open windows of opportunity for niche alternatives to compete for attention and influence.

3.3. Socio-technical landscapes

The macro-level socio-technical landscape provides a highly structural context for both the regime and niches. The MLP landscape includes processes that span societal functions and unfold autonomously of particular socio-technical regimes. Landscape processes include environmental and demographic change, new social movements, shifts in general political ideology, broad economic restructuring, emerging scientific paradigms, and cultural developments. Landscapes provide an influential backdrop with ramifications across a variety of regimes and niches: providing gradients and affordances for how to go about establishing socio-technical configurations that serve societal needs (Geels and Schot, 2007).

Landscape changes are a source of pressures for change on the regime level; they prompt responses from within the regime; and they generate opportunities for niches. At times, landscapes can work to reinforce regime trajectories. At other times, landscape developments place some regimes under considerable stress in ways that undermines satisfaction with their performance, and prompts consideration of niche alternatives.

Regimes are increasingly confronted with new sustainability criteria which were never considered during their installation. Growing environmental awareness is a socio-cultural development that can be considered a landscape process, and which is questioning the performance of multiple regimes, whilst generating opportunities for niches. These are the kinds of multi-level processes that sustainability analysts seek to map and understand, and which policy-oriented advocates try to instigate and govern.

3.4. The allure of the MLP

As our concern for sustainable development has broadened, so the demands on innovation have become more profound and pervasive. Whatever the specific feature of sustainable development under consideration (e.g. deep cuts in greenhouse gases, step change improvements in resource efficiency, delivering the Millennium Development Goals)—the need to escape lock-in, deflect path dependencies and transform socio-technical regimes becomes paramount. The history of innovation studies for sustainable development can be explained as a process of linking broader analytical frameworks to successively larger problem framings.

The MLP satisfies this logic. It argues 'normal' innovation patterns reproduce broad socio-technical regimes. Regime shifts occur through inter-linkages and interactions between multiple developments on three levels. These involve the rise of both strong socio-technical alternatives in niches *and* favourable openings in regime selection environments. The latter is associated with the unsettling of regimes arising from landscape developments. Throughout, it is crucial to recognise these transition processes involving purposeful actors in normative questions operating through structured relations (Rip and Kemp, 1998; Smith et al., 2005; Geels and Schot, 2007).

The allure of the MLP is that it provides a relatively straightforward way of ordering and simplifying the analysis of complex, large-scale structural transformations in production and consump-

tion demanded by the normative goal of sustainable development. Its conceptual repertoire links specific innovation activities configured in niches with structural transformations in regimes. Its terminology of niche, regime and landscape provides a language for organising a diverse array of considerations into narrative accounts of transitions. However, such abstract parsimony carries potential pitfalls which have to be approached with care. There is a tension between appreciating the bigger picture whilst maintaining a tractable parsimony in analysis. The MLP may help people simplify and intervene reflexively, but must not become counterproductively simplistic in its abstraction (Sayer, 1992).

The existing literature contains some cautionary criticisms and some responses. Key contributions have appeared in *Research Policy*. These are picked up in Section 5, so only some brief remarks are made here. Hommels et al. (2007) question the importance and desirability of niche protective space compared to the significance of immediate exposure of novelties to the selection environments prevailing in regimes. Smith et al. (2005) caution against too much emphasis in niche-derived agency in transitions, arguing that incremental reforms in regimes can lead to radical transformations over the long periods under consideration. They suggest a typology of transition pathways (also, Geels and Schot, 2007), and suggest ways that power and agency could be incorporated more centrally into MLP analysis. Shove and Walker (2007) question whether sustainable transitions are really as tractable to policy-makers as implied in some interpretations of the MLP (Rotmans et al., 2001). Like Smith and Stirling (2007), Shove and Walker call for a more reflexive and politically informed appreciation of the way these systems are socially constructed. Markard and Truffer (2008) consider how the MLP can be positioned much more explicitly and fruitfully in relation to technological innovation systems, which reflects the flexible possibilities for the MLP. Genus and Coles (2008) are critical of this flexibility, arguing that there has been a lack of (methodological) coherence in empirical studies using the MLP. The contributions to this special section pick up on many of these issues, and identify others too (such as the geography of transitions).

4. The papers contributing to this special section

The workshop from which contributing papers were drawn was prompted by the debates above, and attracting a growing network of researchers. In Section 5, we discuss challenges presented by the contributing papers and the wider literature. Before doing so, we introduce each paper here.

Philipp Späth and Harald Rohracher use the MLP in prospective mode to consider efforts for sustainable energy autonomy in Austrian regions. They are interested in the coalitions of stakeholders formulating visions for sustainable energy niches in their region. They consider how these visions are formed in the context of increasingly less favourable attitudes towards existing energy regimes. The institutionalisation of regional visions is found to exert an influence over the promotion of alternative niches and other transition processes. As such, their analysis emphasises the roles of discursive and institutional processes in the constitution of regime transformation.

In contrast, *Maurie Cohen*'s paper considers a niche developing in the opposite direction to sustainable energy ambitions. He uses the MLP to explain a personalised aeromobility niche in the US. It is a sobering reminder that not everyone shares even a very general vision for sustainable transitions. Problems within the current mass aeromobility regime relating to passenger convenience and comfort, coupled with organisational and technological innovation, are providing opportunities for personalised aeromobility: precisely at a time when aviation emissions are amongst the fastest growing contributions to climate change.

In contrast to recommendations for nurturing sustainable niches, Cohen's analysis poses the challenge of discouraging unsustainable niches in the making, and whose relative relationship to the regime advantages them compared to the greener alternatives.

Mobility is one of the case studies in the paper by *Elizabeth Shove and Gordon Walker*; this time looking at the congestion charging experience in London. They adopt practice theory as an alternative to MLP thinking about transitions. Practice theory emphasises the constant interplay of technologies, meanings and people in everyday practices. They argue it is the aggregation of these thousands of practices in response to (or despite) the congestion charge that effectively constructs the new mobility regime in London. A second case study analysis into transitions in cleanliness, specifically showering, emphasises that transitions perspectives, have to attend to the destabilisation of entrenched consumption much more assiduously.

London pioneered the large-scale implementation of a congestion charge. Many other local authorities and stakeholders in cities around the world also seek innovative, sustainable infrastructures and services. *Hodson and Marvin* consider the ways the MLP can help analysts make sense of city-based activities. They discuss the position and role of cities as niche pioneers and as bearers of sociotechnical regimes. Analysis considers the extent to which cities can shape socio-technical transitions and effectively carve out their own sustainable destinies. There are parallels here with Späth and Rohracher's paper. Place-based considerations of agency in sustainability transitions emphasise questions of geography and scale, and how processes reproducing niches, regimes and landscapes are spatially (and temporally) distributed across policy jurisdictions at different scales.

The penultimate paper to this special section considers producer responsibility initiatives by the European Union that attempt to induce radical changes in the production and consumption of electronic products. The manufacture, use and disposal of electronics are highly dispersed (often beyond the jurisdiction of the EU). *Hagaleskjær Lauridsen and Jørgensen* use the MLP to delineate and explain changes in electronics goods regimes, and that helps explain why this single measure actually led to innovation in the more tractable waste regime, rather than eco-designed electronics.

Effectively, each contribution to this special section is zooming into specific aspects of the MLP. Whether formulating sustainable visions and niches (Späth and Rohracher), studying unsustainable niche-regime developments (Cohen), emphasising everyday practices in regime reproduction (Shove and Walker), the role of cities in transitions (Hodson and Marvin), or the insights the MLP provides for specific policy measures (Hagaleskjær Lauridsen and Jørgensen). In the final contribution, *Frank Geels*, a pioneer in MLP thinking, considers how other social theories can be brought in to enrich these specific aspects. He relates the ontologies of different social theories to sustainable transitions. He uses this to reflect on the development of the MLP thus far, and the potential for cross-overs with compatible theories. Frank concludes that the MLP provides a device for organising the complementary analysis of specific transition processes using different social theories.

5. Research challenges in this special section

A number of research challenges associated with the MLP or sustainability transitions arise from these contributions. The purpose in this section is to elaborate upon some of these research challenges, and contextualise them within the literature to date. These research challenges are

- relations between the conceptual levels of niche, regime and landscape;
- plural regimes and niches in interaction;
- the geography of transitions;
- empirical operationalisation of concepts; and
- governing regime transitions.

The first four of these challenges relate specifically to the MLP, whilst the last relates to sustainability transitions more generally, whether one uses the MLP or not.

5.1. Relations between niche, regime and landscape levels

The MLP posits that the way niches, regimes and landscapes interact determines the characteristics of a transition. Cohen shows in detail how a variety of landscape tendencies entrench growth in aeromobility. Simultaneously, aeromobility regime dynamics exhibit features that make mass aeromobility less attractive to particular users. As a result, a variety of entrepreneurs have launched novel modes of personal aeromobility. Cohen argues that a crucial factor in the influence of the personal aeromobility niche is the fact that it provides a new hybrid for the aeromobility regime, rather than challenging that regime. Cohen's focus is similar to a scheme proposed by Raven (2006), who explains niche influence by considering the stability of the regime *relative to the stability of the niche practice*. However, this need not mean the aeromobility regime is equally susceptible to all robust niche alternatives (like high-speed rail). Cohen's niche case exploits regime openings successfully because the resulting hybrid reinforces regime actor interests rather than empowering radical transitions.

The specific mechanisms underpinning these interactions prove to be far more complex than early versions of the MLP implied. Successful niches exert influence not solely by growth and displacement of the regime, but more often we see a variety of forms of synthesis and reaction between niche elements and regime components (Geels and Schot, 2007). Elements of a radical niche practice can be co-opted by a regime without unduly unsettling and transforming it (Smith, 2007). Distinctive boundaries between niche and regime become less clear empirically as the MLP implies.

Typologies of multi-level interaction and transition pathway have been developed (Smith et al., 2005; Geels and Schot, 2007). Whatever the merits and drawbacks of these typologies, they remind us that each transformation is historically contingent. It is reasonable to anticipate environmentally sustainable transitions following diverse pathways. Frank Geels' article argues these niche-regime relations can be better analysed by considering how other social theories deepen the focus on specific causal mechanisms. A structuralist ontology could, for instance, shed light on why organic food has been co-opted by the food regime rather than transformed it; though reactions to capture have spawned localised organic configurations that continue to challenge regime practices (cf. Smith, 2005). The MLP serves to keep these deeper investigations and theorisations in context and helps relate them to one another.

5.2. Plural regimes and niches in interaction

The contribution by Erik Hagelskær Lauridsen and Ulrik Jörgensen underscores the need to consider interacting regimes in transitions analysis (see also Raven and Verbong, 2007). The response of consumer electronics businesses to EU producer responsibility policy has been to work with waste firms to innovate materials handling procedures (i.e. alter the waste regime), rather than redesign socio-technical configurations in consumer electronics. Whilst probably better than earlier disposal practices (though

Hagelskær Lauridsen and Jörgensen have their doubts), the waste management innovations prompted by the WEEE Directive are not contributing to electronics eco-designs. The difficulty was not that policy mobilised both regimes, but that it did so in a way that rendered sustainability logics in the electronics regime subordinate to the business logic of the waste regime. The Directive did not address eco-design activities directly, providing little protective space for niche developments in that direction.

Complex reality confronts the MLP picture of a homogenous incumbent regime challenged by a self-evidently sustainable niche. In practice, more or less (un)sustainable niches contend to influence regimes in interaction. Cohen's article suggests analysis of green niche dynamics consider them not just in the context of the current regime, but also in competition with unsustainable practices in niches more closely aligned with the interests of the regime (see also Geels and Schot, 2007). Others have also argued that sustainability analysis must include the counter-veiling effects of unsustainable transitions in the making (Shove and Walker, this issue). There is a *contest* between various niches, each positioned differently in relation to regimes (Scoones et al., 2007). The challenge is whether the overall performance of different niches in interaction with regimes can be recognised sufficiently early to pre-empt lock-in to unsustainable developments. Uncertainties inherent in the co-evolution of niche novelties and regime elements suggest an added dimension to Collingridge's dilemma (Collingridge, 1980).

Considering niches and regimes under conditions of plural competition re-introduces some complexity back into the MLP. Shove and Walker go even further, and argue that even a plural framework fails to capture the sheer complexity and contingency of sustainable and unsustainable developments. Their practice-oriented view perceives countless everyday activities continually reconstituting and reproducing fluid socio-technical configurations. Partitioning these practices into different niches and regimes misses the point that systems (of practice) are always in transition.

Nevertheless, Shove and Walker do recognise patterns and stabilities in daily life. The question is whether patterns of practice can be usefully associated with niche and regime concepts. Some peoples' practices involve greener forms of socio-technical configuring than forms common to the majority of practitioners. Can we aggregate greener socio-technical practices into different niches; and are some practices so routine, stable and pervasive that they constitute a regime? Moreover, practitioners are limited in their capacity to configure by the institutions and infrastructures in which they are situated (Hand et al., 2005). So whilst practice theory forces a more careful analysis of the constitution of niches and regimes, we feel one must not disregard the regimes that make available the material elements of a practice, and their institutions that structure the repertoire of possible practices.

5.3. The geography of transitions

The MLP is interested in the socio-technical transformation of 'societal functions'. The role of places and spatial scales in these transition processes has not been an explicit issue of concern. The tendency has been to presume regimes operating at a national scale, perhaps for reasons to do with nation-state policy audiences. Yet in practice, we see many places, such as villages, cities and regions, wondering how they can transform their mobility, energy, waste, housing and other systems into more sustainable forms. They confront processes that operate beyond their jurisdiction, e.g. the ownership of local infrastructures by multi-national utilities, investments from globally mobile capital, niche alternatives promoted by global civil society, a neo-liberal ideological landscape, or the standards for connecting regime components set by international committees. Clearly, this geography matters for sustainable

innovation, but research is only beginning to explore how this geography influences transitions.

Two contributions to this special section anchor their analysis of transitions in places. Neither the study of Austrian energy regions by Späth and Rohracher, nor the analysis of world cities by Hodson and Marvin, presumes a complete analysis of the geography of transitions. But each does urge the MLP to appreciate the multi-scalar characteristics of its conceptual levels, and to consider the consequences for analysis. Their articles suggest that paying more attention to the places were (distributed) regime changes encounter a variety of niche experiments will yield additional insight into the relations between niche dynamics and unsettling regimes.

Hodson and Marvin consider the multi-scalar challenges confronting world cities seeking to sustainably develop the socio-technical regimes upon which they depend. The MLP provides a useful framework for understanding the success of city strategies towards either autonomy from or integration with other places. These strategies, if successful, require transformations to multiple regimes. Crucially, they are predicated upon a re-scaling of regimes in ways that make them more amenable to the collective will and innovative activities of city-scale actors.

The importance of specific sustainability visions for mobilisation and coordination is important here. The production of these visions needs to engage, mobilise and coordinate actors across scales, and must help (re-)define and align territorial and regime interests. Hodson and Marvin point to the role of mobile intermediary organisations operating between cities and the spatially distributed regimes upon which city strategies depend. Showcase projects that demonstrate and develop niche socio-technical configurations are also identified as important. These showcases satisfy the local need, whilst promising exportable lessons, products and services.

Vision and coalition building processes are at the heart of the analysis of Austrian energy regions by Späth and Rohracher. They emphasise two advantages for places in the negotiation of shared visions. First, places bring meaningful historical and social narratives into the realisation of abstract goals. They generate regionally relevant visions whose symbolism and specificity carry greater moral authority as a result (e.g. 'energy security' cf. 'protecting Murau by building a local bio-energy economy'). Second, regions provide a 'warmer and more fluid ground' for political deliberation (Healey et al., 2003, p. 86), where place-identity (reflected in 'public sentiments'), local knowledge and relational resources may be mobilised for innovative practices (Healey et al., 2003, p. 86; cf. Schön and Rein, 1994, pp. 176–178). However, this is an empirical question. There will be places so riddled with problematic power relations and factions that warm and inspiring sustainability visions do not hold.

Aspiring cities are joining together to lobby for support at the international level (Betsill and Bulkeley, 2008), and these networks can nurture the development and diffusion of niche alternatives by connecting sustainability projects together. Nevertheless, it is asking a lot of city or regional scale visions to mobilise coalitions capable of unilaterally transforming regimes, especially in cases where influential regime reproduction operates beyond the city or regional scale. The WEEE Directive illustrates some of these scalar difficulties. Innovations in the gathering and processing of wastes close to points of disposal seems easier compared to coordinated ecological redesigns across spatially distributed production and consumption chains. In a sense, the response to the producer responsibility policy has been to develop an end-of-pipe regime, rather than fundamentally clean up the electronics regime. This is not solely down to geography, but part of the explanation lies in the spatial distribution of the regimes and their (lack of) congruency with the political jurisdictions trying to induce a transition.

5.4. Empirical operationalisation—a need for reflexivity

Making the core concepts of niche, regime and landscape operational for empirical research is a question of bounding, partitioning and ordering the system under study. Any attempt at bounding and analysing complex, emergent socio-technical systems will necessarily be partial, situated and temporary (Scoones et al., 2007). Whether drawing upon qualitative evidence or quantitative measures based on indicators, there is considerable work to do in formalising the MLP into more detailed methods (Haxeltine et al., 2008). There are few widely shared analytical rules for cutting into the complex configurations under study and abstracting an objective socio-technical system (Genus and Coles, 2008). As Geels points out (this issue), formal quantitative approaches may be limited to relatively stable socio-technical situations where parameters and characteristics are well known. However, the majority of transition studies, like those in this special section, address emergent and reflexive phenomena and find qualitative narrative accounts helpful.

Of course, transition research is not unique in its sensitivity to analytical framings. The instrumental purpose for sustainability transitions research accentuates the implications, since the ways in which these concepts are used has repercussions for transitions as a governance activity. Shove and Walker (this issue) emphasise how socio-technical 'systems' are constructed by subjects engaged in configuring, including researchers (see also Smith and Stirling, 2007). Philip Späth and Harald Rohracher convey this quite vividly for the case of Austrian energy regions. Differently situated participants in the region brought their different understandings and interests in energy provision to the negotiations. A shared framing of the current energy regime and sustainability issues was negotiated. Participants envisaged alternative niche configurations, and sought a degree of congruency between the interests involved. Common framings of the 'system' are reached through negotiation, informed by diverse knowledge and experience of the way the 'system' satisfies particular human needs (which are themselves understood in different ways).

The contributions suggest it is not precise definition of niche, regime and landscape that is paramount, so much as what each conceptualisation does. As with other critical social science activity (Sayer, 1992), the point of sustainable transitions research is to engage subjects in processes of reflection in ways that feed back into their practices, contributing to a re-orientation towards sustainable development (Loorbach, 2007). Thus the operationalisation of the MLP empirically requires reflexivity on the part of the analyst and sensitivity towards the task in hand.

5.5. Governing sustainability transitions

Regimes are a *de facto* form of governance in the sense that they structure and order the interaction *of* material artifacts and social processes (Rip, 2006). In contrast, here we consider *purposeful* governance *for* sustainable development, and analysis for deliberate policy aiming to transform regimes. Geels and Schot (2007) suggest that socio-technical rule sets are constantly maintained and re-made through the interactions of actors in regimes and niches. Rules do not solely constrain but also enable actors to participate in socio-technical system development. In their view, social agency for sustainable development derives from an ability to modify and replace rule sets.

The contributions in this special section suggest rule-based processes need not be so clear cut. Socio-technical regimes can prove resistant to governance intentions (e.g. the congestion charge and producer responsibility). Any policy measure, no matter how well it is understood, creates diverse responses that are difficult to know precisely beforehand. Indeed, part of the explanation for the shape

of the policy measure rests upon earlier processes and problems emanating from the socio-technical regime. There is a need to explain how and why individual agents are able to reform the rules in desirable directions, in the context of regimes and niches, thus dealing with the politics essential to transitions.

The London congestion charge discussed by Shove and Walker is a policy whose ultimate effect is not solely determined by political authority, but also by adaptations to the mobility practices of Londoners and visitors. This is obvious. Yet for policies to gain support, they need to underplay this problem of anticipation and pretend they are capable of assuring desired re-configurations (e.g. Lindblom, 1965, 1990; Majone and Wildavsky, 1978; Elmore, 1979). Shove and Walker's study emphasises an additional tendency in transition policies, which is to make an a priori us-them distinction between governors and governed. This neglects the role of both sides in explaining changes in socio-technical transitions. The analysis of regime responses to the WEEE Directive by Hagelskær Lauridsen and Jörgensen reinforces this point. Rules, incentives and norms can be altered by those governing (us), but it is the responses of many others (them) involved in socio-technical (re-)configuration that result in, say, the growth of a niche, or the unsettling of a regime. The success or otherwise of a policy measure rests in the way governors conceive the operation of the socio-technical regime in the first place (Smith and Stirling, 2007).

One can go too far in this kind of analysis. Only a handful of people in London were in professional and institutional positions to instigate the congestion charging policy (e.g. the Mayor and his advisors). Certain institutionally privileged actors are able to make more forceful changes to multi-level dynamics compared to many others that play a (less strategic) role in reproducing those dynamics (Smith et al., 2005). The structural power of the former derives from this contribution to maintaining the rules, infrastructures and values underpinning socio-technical practices.

But this position is not assured. The resources needed to induce significant socio-technical change are widely distributed. This distribution obviously includes the regime membership; but it can involve resources in actor networks beyond the regime (e.g. knowledge about alternatives amongst niche participants; legitimacy issues deriving from social movements). Contextual developments in the landscape can shift interdependencies between actors. Power relations alter. New discourses generate new expectations about the adequacy of regime performance, such as its sustainability, and contribute to a re-ordering of priorities. The status of resources and positions of different actors are cast in a new light, as the Austrian case indicates.

It might be difficult to know the precise consequences of a policy measure perfectly in advance, but the centrality of certain actors in the reproduction of regime and niche socio-technical configurations, and their likely responses to governance interventions, does suggest we can develop informed expectations about the contribution of various policies to sustainability transitions. Governance schemes that take socio-technical complexities into account, and yet retain a sense of which niche-regime-landscape reproduction processes are significant for transitions, and that target their policy attention on the key players accordingly, are more likely to generate effective transition policy. The MLP argues portfolios of policy measures need to work across: the destabilisation of incumbent regimes (so that opportunities for structural change increase); the promotion of radical green niches (so that the portfolio of promising solutions broadens); and processes for translating ideas and practices from niches into mainstream settings.

6. Conclusions—towards a future research agenda

The evolution of the MLP in the context of innovation studies and sustainable development raises some challenging analytical and practical issues. Many of these remain open and point towards a vibrant, stimulating and challenging research agenda for the future. In the discussion here, we have argued that innovation studies have contributed considerable conceptual insight. This contribution will continue, but, as the challenges in Section 5 illustrate, this will most likely be made in dialogue with other disciplines, such as political science and geography. In our view, a number of future research themes become prominent. These are niche dynamics, unlocking regimes, spatial aspects of transitions, methods to map transitions, politics of transitions, and interlinkage with dynamics of governance.

6.1. Niche dynamics

Future research should continue to improve our understanding of niches, in terms of their development and their wider influence. A first issue is to elaborate the conceptualisation of niches as 'protective spaces' in which novel socio-technical configurations take a hold and start to develop. What exactly makes a niche protective? In which ways are niches different from broader selection environments? Over what kinds of space does the protective effect extend (a geographical region, a local jurisdiction, a cultural milieu)? How can evolutionary theories help substantiate the ecosystem metaphor that informs the niche concept?

A second issue regards the process by which niche innovations move beyond the initial protective space. How are learning-by-doing experiences transferred beyond the niche context? How do practices (embedded configurations) replicate, scale-up or translate into other contexts of application?

A third issue is to move analysis beyond instrumental learning and expectations about the niche socio-technical configuration. An important dimension of niche dynamics is the development of a social constituency for alternative projections of socio-technical development. Successful niche experiments feed actor networks with shared expectations, inform the identities of the supportive coalition, and help orientate interests and social norms. How do such processes of constituency building take place? Under which conditions do niche actors come to reflect a common agenda and mobilise? How do they seek to stretch and shape the space in which they can prosper (by engaging with agendas of public policy, regulatory frameworks, technical standards and finance)? That is, how does the niche perform as a political actor?

A final niche issue for future research is their interaction with other niches, and the consequences of plural niches in the context of a shared regime 'other'. Competing or complementary niche developments occur in parallel. How are any interdependencies reflected in the strategies of niche actors? How do dynamics of contestation across niches play out in a context where sustainable development is an inherently ambiguous and contested societal concept?

6.2. Unlocking regimes

Our second suggestion for future research is at the regime level. In contrast to the large body of research on path-dependency and lock-in in socio-technical dynamics, relatively little is known about processes and mechanisms for accelerating the unlocking of socio-technical regimes. How do regimes open up, erode or decline? A related issue here is with the roles and strategies of particular actors in these processes. Taking public policy, we observe a reluctance to seriously consider how to unsettle and unlock established regimes. Perhaps links to the decline of politically salient industries makes it too great a risk. But what are the conditions in political economy that allow an accelerated dismantling of unsustainable socio-technical structures, at the same time as creating space for sustainable alternatives to develop? Public policies tend to positively engage with promising opportunities (niche building)

in isolation. Understandably, the politically contentious, coercive dark side of sustainability transitions, principally putting pressure on regimes, is done with much greater timidity. How do entrenched regimes, upon which many of us are dependent, lose their economic and social legitimacy? How do shifting alliances of actors alter power balances in favour or against a certain socio-technical regime? What is the role of landscape processes such as shifting political ideologies, waves of investor speculation, institution building and ecological change?

6.3. The spatial aspects of transitions

The MLP provides a useful heuristic for considering the temporal aspects of transitions. It does this by considering multi-level processes of socio-technical structuration constituting specific functional spaces (e.g. mobility, energy, housing). Our third suggested area for future research is how the functional socio-technical spaces of niche, regime and landscape relate to other dimensions of space, such as territorial, administrative and communicative spaces (and their particular topologies). The boundaries of a socio-technical regime are not necessarily identical with those of a geographical landscape, a nation state or a social community. How do socio-technical spaces relate to and cut across these different spaces? How do emerging communicative spaces such as global publics or transnational networks of entrepreneurs and professionals connect to niches and regimes and establish linkages between them? Some important insights might be expected for sustainability transitions by focusing on both the situated and the distributed qualities of key, multi-level processes.

6.4. Methodology to map transitions

As with any framework, methodologies for rendering MLP concepts empirically operational are critical to its future success. Some in the field are looking for standardised indicators, measures and matrices in order to objectify research on niches, regimes, landscapes and their dynamics of change. Principles for bounding and measuring niches, regimes and landscapes need fleshing out into rigorous criteria. Comparability and systematic accumulation of cases will then build theory. Others wish to keep open the flexible application of the MLP appropriate to specific contexts. The reason given here is that the nature of the problem studied – structural and functional transformation – undergoes change whilst being studied. Methods need to capture the dynamic effects that are produced? Debate about the methods for mapping transitions needs to continue through future research.

6.5. The politics of transitions

Sustainability transition studies are trying to combine evolutionary theories of socio-technical change with theories of agency and strategic decision-making. Future research needs to develop the MLP's "quasi-evolutionary" approach further, and provide deeper conceptual guidance on how to combine (co-) evolution and agency. How does agency play out in variation and selection processes? To what extent do variations and selections arise from the decisions of particular (networks of) actors? How do decisions and action strategies reflect and anticipate selection environments and evolutionary dynamics? It is important to look beyond the "usual suspects" here (R&D labs, industry, science, and public policy), but bring in the role of other agents too, such as lifestyle milieus or social movements who may have an important role for shaping the selection environment beyond the market.

A broader analytical view on agency makes salient political questions about the interests and sources of power shaping selection environments and generating variations. Studies are beginning to consider coalition formation around different niches, and the lobbies for different kinds of socio-technical transitions (domestically and internationally). Social movements are important expressions of and catalysts for changing values and identities, but how do they engage with socio-technical systems and seek to transform them?

6.6. Opening the black-box of public policy

Our last suggestion for future research is to incorporate the analysis of policy processes as part of the study of innovation in socio-technical systems. The literature, including this special section, refers frequently to policies that engage with socio-technical change, be it through market interventions, R&D funding, provision of platforms for strategic niche management, or regulations unsettling regimes. However, so long as policy remains an external force or factor of influence, then the conditions for those policies to be put in place continues to be obscure (Voß et al., 2009). Just how independent are policies from what is going on in the socio-technical realm? Papers in this special section point to multiple interlinkages between actors and institutions of markets, technology and societal demand with those of market regulation, innovation policy, and environmental governance—be it through education, professional ties, personal overlap, cultural paradigms, joint ventures, cooperative agreements, cross-financing, lobbying, revolving doors, or common political agendas. There are long-standing literatures on regulatory capture, government-industry relations, clientelism, iron triangles, policy networks, and discourse coalitions that can help us ensure analysis of socio-technical regimes and public policies are more deeply intertwined.

6.7. An open agenda

Our list of future research for the MLP is neither exhaustive nor exclusive. The MLP is bringing together a growing network of international researchers with a variety of agendas (now formalising in an international Sustainability Transitions Research Network). If a sustainability transitions perspective provides a problem focus, then the MLP provides a helpful framework for organising the broad interdisciplinary analysis that is needed. It is clear that this is work in progress. There is considerable scope for innovation studies to contribute further; just as it did in the genesis of the MLP framework. Ultimately, the future depends on whether and how research can satisfy growing demand by policy and society to better understand broad directions of socio-technical change, and how dialogue can be reflexively guided towards particular sustainability qualities.

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