A Critique of Geels' Multi-level Perspective of Technological Transition

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Abstract

In recent years numerous articles have been published which advocate a multi-level perspective (MLP) for the analysis of long term technological transitions. This paper reviews current transitions research and considers the limitations of the MLP which need to be addressed to enhance understanding of processes of innovation affecting the transformation of technology and society. The paper suggests ways in which the MLP may be effectively rethought, based on more thoroughgoing application of a co-evolutionary concept of technological transitions, discussed with reference to microgeneration of energy in the UK.

Keywords: Technology; Transition; Multi-level Perspective; Energy Policy; Microgeneration

1. Introduction

The theory of technological transitions advocates the periodic wholesale replacement of embedded socio-technical practices by radical innovations. More recently potential for transition towards environmentally sustainability has been advocated in the academic and policy arenas. Transition theory is an approach that has the potential to provide a better understanding of this. Within transition theory an emerging and much published strand of work pertains to Geels' (2002) advocacy and application of a multi-level perspective (MLP) to the analysis of the development and entrenchment of technology in society. Previous case study research has, for example, focused on both historically based and more recent case studies.[1] Such interest indicates the potential use of the transitions approach in analysis of ongoing socio-technical change. In this paper we will consider this potential in the context of an emerging, if under-researched issue relating to the transition to sustainable energy technology, for example concerning the role to be played therein by microgeneration and community-level energy generation (DTI, 2003; 2006). This has been highlighted in recent policy statements by the UK Government, for instance, which considers that 'individuals, households and communities have a crucial role in tackling climate change' (DEFRA, 2006).

Whilst there has been much published on the subject of the MLP in recent years, it is an approach that requires theoretical reformulation and empirical validation; to date there has been little related published research based on the collection and analysis of primary data. In this paper it is intended to subject the MLP to a critique, which will shed light on the inapplicability of the approach to analyse technological transitions effectively. The paper highlights certain conceptual and methodological limitations of the MLP and takes in issues connected with how to analyse current technology developments, as distinct from the preoccupation with retrospective analysis of case studies often found in the literature on transitions. It addresses the steering of technology by the State and others in society, and the relation of this to 'bottom-up' activities in niches of technology development, and the question of the compatibility of niche innovations with technologies in the incumbent socio-technical regime. The paper proceeds in the following manner. Firstly, in section 2, previous research on transition theory, and especially that on the MLP, is outlined and reviewed. Limitations of previous work on the MLP are identified. Subsequently section 3 considers whether the multi-level perspective should be rethought or eschewed, and the matter of whether and how the approach could be revised to enable more effective analysis, possibly of ongoing phenomena. The implications of the foregoing for future research, together with some suggestions regarding the direction and content of that work are discussed in the conclusion, in section 4 of the paper.

2. Previous research on transition theory

The starting point for this review of work advocating a multi-level perspective of technological transition is discussion of the concept of technological regimes, the development and extension of which was an issue of initial concern for proponents of the MLP. The concept of technological regime was first proposed by Nelson and Winter (1982) to refer primarily to the beliefs and prevailing successful designs which predispose innovators in firms towards development of certain apparently marketable or feasible options but away from other less attractive options. Later, Kemp, Rip and colleagues defined their notion of technological regimes more broadly, in so doing addressing criticisms of Nelson and Winter's formulation that it overly emphasised design heuristics and cognitive rules within firms, whist underemphasising the

embedding of technology in society (Geels, 2005c; Raven, 2004; Rip and Kemp, 1998). For Rip and Kemp (1998: 338):

"a technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems – all of them embedded in institutions and infrastructures. Regimes are intermediaries between specific innovations as these are conceived, developed and introduced, and overall sociotechnical landscapes."

Developments in the area have much to do with the work of Geels (2002; 2004; 2005a; 2005b; 2005c; 2005d; 2006a; 2006b; 2006c; 2006d; 2007; Geels and Raven, 2006; Geels and Schot, 2005; 2007; Verbong and Geels, 2007), who sought to widen the focus of analysis typically associated with the sectoral systems of innovation approach. Geels (2002; 2004) extends the general concept of technological regime, while advancing the notion of 'socio-technical regimes'. As it has been applied thus far, this strand of transition theory proposes a multi-level perspective (MLP) of transition in which researchers analyse past episodes of transformational innovation at macro-level (landscape), meso-level (regime) and micro-level (niche) (see Figure 1). In general these have attempted to explain processes of radical development of novel technology whose diffusion pattern produces a new set of socio – technical relations, which largely replace the existing general social practice. A benefit of this work is the attention accorded to the previously neglected role of 'outsiders' (c.f. van de Poel, 2000) or users in technology development and to the role of interactions of various actors, socio-technical systems and action-conditioning (though not determining) rules therein. It is not however an approach that has been employed primarily to explain or to predict *ex ante* or concurrent developments in specific socio-technical arenas, a shortcoming to which this paper will return.

In Geels' multi-level perspective the stability of existing socio-technical systems occurs through interaction between the material aspects of the system, embedded actors and organisational networks, and the rules and regimes which guide perceptions and actions. The path dependence which locks in existing socio-technical systems is described as occurring at the meso-level of analysis. Here there is a patchwork of regimes which make up the 'deep structure' of socio-technical systems, only one of which is the technological/product regime. The others are the: science regime, policy regime, socio-cultural regime, and the users, markets and distribution networks regime. These regimes represent different social groups which share various kinds of rules (regulative, normative and cognitive), which make each regime somewhat distinctive and autonomous. Yet the regimes are interdependent to the extent that rules are connected between regimes as well as within them. Hence designers, users and others have their own ideas about the benefits and functionality of new technologies, and what the market wants, views of which may concur in relatively stable socio-technical systems. However, the emergence of deviations from the current regimes is prompted by landscape pressures, such as increased awareness of the need for environmentally sustainable energy (see Figure 2). Radical innovation occurs typically at the micro-level in niches, either in response to landscape changes or in a bottom-up fashion. Niches can act as spaces for experimentation protected from market selection pressures, or to enable social networks supporting radical innovations to be built up. Kemp, Rip and Schot (2001) consider that such niches may be strategically managed in the sense that they can be used to nurture fledgling technologies that may offer substantial environmental benefits in the future at a time when there future is most uncertain. These niches can then provide opportunities for society to learn about: the functionality of alternative designs, user preferences, appropriate public policies, and so on. Within niches, rules and social networks will be both less clear and more uncertain than in established regimes and it is likely that, due to mismatches with existing regimes, radical new socio-technical systems cannot easily break through (Geels 2004). However, Berkout et al (2004) are critical of the dependence put on the niche level as a driver for socio-technical change and question the fundamental role attributed to niches in the MLP.

Generally, in MLP research it is argued that transitions commence when: a prevailing socio-technical regime starts to display significant problems; a key innovation occurs that will become a dominant design; and first or early adoption of the transition technology takes place. The end of a transition is the point when the new socio-technical regime reaches the point where 'social embedding' of the nascent technology/ies takes hold. In order to be considered transitional a technology has typically been identified to be a radical innovation, and to have demonstrated its impact over the longer term (in these case studies between 40 and 90 years). Geels and Schot (2005) identify 5 transition paths plus a path which does not represent a truly 'radical' transition, but rather system renewal characterised by constant incremental innovation:

Transformation – socio-technical regimes that change without recourse to one dominant technology (e.g. in the case of waste management in the Netherlands, 1960-2000);

Technological substitution - a radical technology replaces an existing technology creating a new socio-technical regime (e.g. steam replaces sail 1807-1890, particularly in the UK);

De-alignment and re-alignment – existing regimes begins to develop problems, competition between new technologies to solve these issues results in the emergence of a winner (e.g. development of the automobile sector in the USA, 1870-1930);

Opening up new domain – successful socio-technical system building provides new social function (e.g. development of aircraft industry in the USA, 1900-1940);

Reconfiguration – system changes in many technologies and organisation changes (transition from batch to mass production in the USA, 1850 – 1930).

The definition and analysis of transitions is not unproblematic however, as discussed in the following section on limitations on transition theory research.

2.1 Limitations of previous research

A number of criticisms may be made regarding transition theory, consideration of which raises questions about its general (universal) applicability:

(i). A fundamental concern is the paucity of empirical studies on the topic of transition theory/MLP based on the collection of primary data relating to technological transitions now in the making (but see Genus and Nor, 2007, for an exception). Much of what has been done that has been referred to as empirical has been produced by one author (Geels), who has in fact relied on secondary sources for his case studies (as have Raven, 2004; Raven and Verbong, 2004a; and Rotmans et al, 2001, for example). The case study research in general has been conducted in a very unsystematic way, and work invoking Geels' multi-perspective (on which more than a dozen journal articles have been published since 2002) has not fully or clearly applied the MLP. There has, moreover, been a failure to specify the model or framework employed in the research conducted, and to be explicit about which parts of the framework are more or less easy to operationalise - especially in relation to the specification and delineation of different types of regimes and rules. Significantly, none of the above-mentioned studies systematically identifies or analyses the meso-level socio-technical regimes said to be central to stability and change in socio-technical systems, not least with respect to the rules and routines said to be central to activities of groups in those regimes (for example see Geels, 2002; 2005a; 2005c; 2006a; 2006b; 2006c; 2006d; 2007; Geels and Raven, 2006; Verbong and Geels, 2007). In sum these comments highlight the need for greater clarity and robustness in the use of multi-level models of technological transition.

(ii). As mentioned above the definition of transitions is problematic, for example in relation to the establishment of the start and end points of transitions.[2] Reviewing the case studies reported in related research it would appear that the characteristics of transitions differ from case to case,

are identified with hindsight and can be represented by different sets of events. What does seem to be typical of transition is for a socio-technical regime to start to display significant problems, at about which time a key innovation occurs that will become a dominant design, which represents first or early adoption of the transition technology (Geels and Schot 2005). However, a transition start is not necessarily comparable with other cases as it is: contingent on the particular case study; difficult to establish without an historical viewpoint; and an outcome of the analyst's decision-making. So, depending on the case in question, the start point of transitions may have different characteristics, which are identifiable with hindsight and can be represented by different sets of events, as demonstrated by the varying start points chosen by researchers of the following cases taken from the literature on transitions.

Waste management in Netherlands (1960/1970) - dominant regime starts to be subject to critique (note the different start dates given by Geels and Schot, 2005; and Raven and Verbong, 2004a);

Aircraft industry in USA (1900) - Wright brothers' demonstration of a working technology (Geels and Schot, 2005; Geels, 2006b);

Steam ships (1807) - first use of the technology (Geels, 2002);

Automobiles (1870) - problems emerging in the dominant regime (Geels, 2005c; 2006d);

The end of a transition also varies in definition across cases (Geels and Schot 2005), e.g.:

Waste management (2000) – at the end of a period of 'rule change' through new legislation enforcing infrastructural change;

Aircraft (1940) – business established, infrastructure development, flight paths etc, and stable socio-technical regime emerged;

Steam ships (1890) – legal, social, technical and infrastructural changes facilitate commercial use;

Automobile (1930) – at the point of growing car ownership, infrastructural change;

Moreover, whether or not a transition has taken place is not a transparent matter. Even stable regimes exhibiting slow, incremental change could exhibit radical change over the longer term. (It could be argued that sustainable technologies would be more readily adopted if they exhibited good social fit and existing regimes could be maintained (c.f. Kemp et al, 1998, Phillimore, 2001)). But if radical change is also part of the ordinary path of renewal or reproduction in some cases it could become difficult to tell one (incremental) path from another (radical) one. Moreover, at the time they take place surely all changes appear to be incremental to the existing socio-technical regime, the radical transition is perceived due to a cumulative outcome from a long period of change with hindsight and analyst interpretation so it should be noted that:

(a). transitions are heterogeneous, long-term effects of socio-technical change;

(b). transitions are limited by and contingent on factors such as time scale, place, technology and social, political and economic context.

In addition, presenting any of these cases in a different way could make them fit a different path, for example steam ships could be said to represent system renewal over time, and aircraft could be presented as in technological competition with airship development in the early 20th century. Both the bicycle and the electric tram could be presented as transitions in their own right with shorter stabilisation periods because all transition technologies could be eventually replaced by radical innovation. For example if Geels (2005c) had limited his analysis of automobile development to the period up the 1920s, would the transition in question have looked like one from foot to bicycle or even bus, rather than one from privately owned horse to car? Certainly the road infrastructure would not have been so well developed. In retrospect the bicycle looks as if it is an intermediate technology, between the horse and car. But the same would be said of the steam ship – lying between sail and modern ship propulsion or even the replacement of sea for air carrying cargo.

This gives rise to issues about the identified transition paths, such as identification of the limits to the number and type of transition paths that can be described? There is, then, a question mark over the definition, conceptualisation and verification of transition paths within transition theory and it is also unclear whether a new unique transition path can or should be identified for each new case study – as it appears at the moment, or whether there are generalities of some kind, universalities prevalent across cases. In effect it looks as if the transitions model offers the analyst, at best, a heuristic if not methodologically transparent device that can be used to organise sets of historical data about long term, complex and competitive technological trajectories (c.f. the view expressed in Geels, 2002). A number of aspects of the research process rely upon choices and interpretations made by the analyst(s), decisions and interpretations about which need to be explicated and justified if the study in question is to be fully understood or subsequently replicated. This explication and justification of the research conducted is something that MLP researchers have neglected to do. The following aspects of MLP research have been the subject of choices and interpretations made by the analysts concerned:

Selection of cases to research - analyst's choice and interpretation;

Collection and attribution of case study information to categories of the MLP - analyst's decision;

Transition start and points - analyst's decision;

Role of technology/innovation - analyst's decision;

Contingency and specificity of case - analyst's decision; and

Path articulation - analyst's decision.

(iii). The retrospective nature of transition theory research has served to privilege the 'needs' of technology (as 'artefact') in terms of adaptation to technological determinants. This gives rise to linear analysis, in sympathy with ideas such as path dependency and technological trajectory. Ultimately, therefore, the result of applying evolutionary theories to innovation as transition theory has done is to play down the role of agency (Smith, 2006; Smith et al, 2005), or strategy, and to emphasise more reactive and unreflective adaptive processes at work. For example 'winning' technologies are viewed as those which have by definition proven their optimum efficiency in a techno-economic sense (despite counter-examples, such as the case of the 'QWERTY' typewriter keyboard (see David, 1985)). The pervasiveness of linearity is betrayed by remarks made by Geels (2005c) regarding the 'dealignment' and 'realignment' of alternative transition paths with that of the 'winning' transition trajectory.

(iv). Another limitation of previous research in the area concerns the employment of an evolutionary historical case study method without acknowledging the debates surrounding the presentation, and use, of such data.[3] Rather, transition researchers have placed undue emphasis on uncritically 'accepted' accounts of the historical significance of certain socio-technical developments. So, the apparently arbitrary nature of transition characteristics might derive from the secondary nature of the historical sources rather than from a primary concern with accurate model building. In effect, then, it appears as if the potential contribution of the MLP transitions framework could be limited to offering a heuristic device that can be used to organise sets of historical data about long term, complex and competitive technological trajectories. This undermines the attempts of researchers using the MLP of technological transitions to align their work with ideas about social shaping of the technology and the co-evolution of technology and society, never mind any notion of tackling issues of conflict or failure in prospective or concurrent analysis of technology development.

(v). A fundamental limitation of the previous work is recognised by Geels, who observes that applications of the multi-level perspective have tended to feature case studies having a 'technology…traditional artefact' focus (2005a: 365). This focus had the effect of neglecting 'transitions with important cultural and societal aspects' (Geels, 2005a: 393), as well as being to the detriment of analysis of co-evolution of technology and society claimed to be central to the

approach. Moreover, it is not clear that all of the aforementioned studies are in fact concerned with the same core research question. For example, Geels' work poses the question of how changes at the level of technology systems occur (systems innovation), whilst other studies such as that of van Driel and Schot (2005) are directed at radical *technical* innovations. This matters to the extent that one is concerned to analyse technology transformation as a social accomplishment, or better to appreciate the heterogeneous quality of technology development, rather than merely to address after-the-fact social implications of technical innovation. Again, the risk is that analysis of transformation will neglect attention to the co-evolution of technology and society, with the effect of underplaying social and cultural aspects of development, which may well be central to transformation.

3. Rethinking transition theory

Transition theory offers in the form of the MLP an approach that potentially may facilitate the analysis of change in socio-technical systems. However, as the foregoing has shown, a proper sense of the extent of its utility is undermined by the absence of primary research employing the MLP, a point which also applies to unacknowledged issues connected with MLP researchers' reliance on the use of a retrospective case study method. Further its contribution has been undermined by a tendency within MLP research to privilege accounts of successful technical innovation, at the same time leaving the 'black box' closed. In addition, foregoing sections of this paper have shown that research employing the MLP has tended to neglect methodological problems associated with the definition and analysis of transitions, and runs the risk of overemphasising the 'technical', whilst neglecting relevant socio-technical and cultural phenomena contributing to system change. Initially, at least, MLP research conceived of technologies, regimes and niches narrowly, and neglected interactions among multiple innovation pathways, regimes, and niches. It thus failed to attend to broader and arguably deeper aspects of ongoing co-evolution of technology/society and discourse building tackled elsewhere, for example in analyses of expectations of future technological performance (Brown and Michael, 2003), although Geels and Smit (2000) do introduce the idea of failed expectations surrounding innovation.

There is an opportunity to interrogate, validate or revise the MLP, something which proponents of the perspective have recognised (up to a point) in the most recent work on the subject. For example Geels has published papers which have suggested specific 'adjustments' to the MLP, whilst Geels and Schot (2007) have responded to specific criticisms relating to the approach's treatment of 'empirical and analytic levels', the role of niches in 'nurturing' innovation, and the neglect of agency. Between them these recent articles have sought to take into account and to address the following: the need to take seriously the role of 'societal' changes in policy, and cultural and market 'elements' of systems innovations (Geels, 2005a); the role of reconfiguration of technology, user practices and so on in system change, presented as an alternative transition 'pathway' to technological substitution (Geels, 2006a, b, c); related to the previous point the extent to which gradual or incremental processes underpin what could appear as radical or major systems change (Geels, 2006c), or the possibility of symbiosis between niche innovations and the incumbent socio-technical regimes (Geels, 2007); the relationship between niches and the mainstream, and differentiation of the concept of niches beyond the merely 'technical' (Geels, 2006a; Geels and Schot, 2007); and the interaction of multiple regimes (Geels, 2006a). Some fundamental issues have yet to be addressed satisfactorily. For example, both Geels and critics of his approach (e.g. Berkhout at al, 2004) continue to neglect a fundamental aspect connected with the issue of how to treat conceptual and empirical 'levels' in the MLP (and also the definition of the boundaries between the various socio-technical regimes therein). The debate has become one

of how to apply different conceptual levels empirically, or how to unpick 'nests' of niche, sectoral and system-wide 'levels' (Geels and Schot, 2007), rather than to question the meaning and significance to action of levels 'on the ground', from the perspective of subjects. And on the topic of agency it is of great interest that Geels and Schot (2007) recognise the role of stable and less stable rules in coordinating action and conditioning values in regimes and niches, being 'in the making' in the latter. They also claim that a multi-paradigm approach to conceptualising agency (on the basis of a concern for: rational choice; interpretation; power; and the deep structures in which fundamental assumptions reside) may be applied beneficially to the analysis of transitions, within a 'rule-based model of action, on which the MLP is based' (Geels and Schot, 2007: 415). Yet the making or unmaking of the various types of rules constraining or enabling actions and the reproduction of related practices central to maintenance or transformation has not been an explicit object of systematic study in MLP research – not in case study histories, and certainly not in any contemporaneous analysis. In both these important respects criticisms relating to limitations of the MLP remain to be answered effectively. Failure to address such criticisms convincingly is likely to hinder the building of a more robust approach to the analysis of transitions.

The above paragraphs have identified modifications to the MLP that have been suggested in the most recent published work of its chief proponent and indicated aspects of the approach in which criticisms remain to be answered effectively. With the latter in mind there are a number of possibilities that could be considered. For example, one could investigate the complementarity of the MLP approach with constructionist approaches such as the social construction of technology (SCOT), and constructive technology assessment (CTA), which on the face of it come from radically different points of view from the MLP (Bijker, 1987, 1992, 1995, Rip et al, 1995). A genuine focus on co-construction of technology as a complementary method of (re) creation of technology in society could be employed, thus informing and potentially bridging transition theory and social constructionist approaches. SCOT emphasises the open-ended character of technology development so as to analyse the potentially many paths or trajectories negotiated between humans and artefacts (Bijker et al, 1987). It addresses the specifics of development for any case and exposes the political processes involved in constructing the notion of best fit between 'technology' and 'society'. CTA (Rip et al, 1995; Schot and Rip, 1997) is an approach that emphasises prospective or real-time study of the interrelationship between the social and technical, which has recently been extended to embrace discursive aspects of technology assessment and development (Genus and Coles, 2005; Genus, 2006). Relevant themes here include the role of discursive capacity in enabling or limiting access to debates and decision-making about the significance, assessment, design and use of technology, and the role of language in mediating interactions of those interested in or affected by developments (Genus and Coles, 2005). Another possibility is to draw on ideas connected with SCOT and CTA to mount an appreciative critique of the MLP. Applying SCOT and CTA to inform and to probe the MLP would more explicitly address - at first hand - interactions among actors shaping or affected by technology development in the regimes apparently central to stability and change in socio-technical systems, as well as to analyse the variety of possible transition paths and technologies prevalent in specific cases. Such approaches would also highlight the interpretability and stabilisation of beliefs about benefits, risks and uncertainties associated with processes of socio-technical change, thus giving rise to novel descriptions and analysis. They could, for example, be employed to compare network interactions and constructions relevant to the emergence and entrenchment of new technologies in society with representations of technological transition suggested by the MLP. A particular contribution of this kind of work would be to open up, on the basis of the collection and analysis of primary data, our view of the multiple patterns in and factors affecting ongoing transitions, to keep alive a view of alternative developmental possibilities and paths rather than to concretise them in an overly reductive way. (See for example

the work done on mapping emergent innovation networks in the field of nano-particles in printing ink and their impact on sustainability in Steward et al, 2006).

Another option is to consider the possibility of linking transitions and network approaches to facilitate the study of emerging sustainable technologies (see Steward, Coles and McNally, 2004; Steward, McNally and Coles, 2005). For example, consider actor network theory (ANT). ANT has a focus on technological change at the micro-level, which Callon (1987: 83) claims is concerned with the "steps from the birth of an idea (invention) to its commercialisation (innovation)". ANT is concerned with description of the links between human and non-human elements in a network (see Latour, 1988; 1991; 1999). Thus, ANT attempts to overcome the boundary between the social and natural world, and to explain the gradual progression of new technology to "describe given heterogeneous associations in a dynamic way and to follow, too, the passage from one configuration to another" Callon (1987: 100). This approach differs from the MLP in its explanation of technological change but has the advantage of exposing the processes of negotiation and enrolment that actors engage in to join a network facilitative of technology-society development. Indeed such a focus could be argued to provide a useful approach to the open-ended study of sustainable innovation. Possibly application of the MLP can help to mediate some limitations of ANT also. For example, the orientation of the MLP towards users and 'outsiders' to technology development could address the criticism that ANT under-represents excluded groups, as well as those with counter or critical perspectives. Further, invoking the MLP, with its concern to paint in the 'landscape' of socio-technical transition, could be a way to counter the lack of contextualisation associated with ANT.

3.1 Researching the emergence of sustainable energy technologies

As indicated in the foregoing paragraph an interesting topical application of a rethought MLP could be to conduct research which brings together thinking about innovation and technology systems with that concerned with environmental sustainability, policy and management (Bell et al, 2007). There is a sense in which we may be going back to future here, to build upon earlier work by Kemp (1994) on just this topic, though with the intention to articulate more clearly models and processes of transition to environmental sustainability. There have been examples of work on the emergence of sustainable energy technologies making more or less specific connections with transition theory and the MLP, and researching factors promoting or inhibiting the entrenchment of new or renewable energy technologies in society. In addition, an unreconstructed version of the MLP has been applied, again within an analysis utilising secondary data, to research ongoing energy transition (Verbong and Geels, 2007). Together these are suggestive of current and potentially future research agenda. For example the UK funded Economic and Social Research Council's (ESRC) recent Sustainable Technologies Programme (STP) which was carried out between 2002-2006, aimed in part 'to identify and explain the social and economic forces that shape, foster or inhibit sustainable technologies' (Monaghan and Steward, 2006: i). One project intended an explicit application of the MLP to the analysis of contemporaneous developments in the area of community energy generation in the UK, though in the event this was not realised. This study (led by Gordon Walker) originally stated that it would 'evaluate the role of community initiatives in…embedding …sustainable energy technologies in the UK', by posing the question of how transition in regimes happens through strategic niche management. In doing so the researchers made explicit reference to transition theory and to Geels' 'multi-level model' of socio-technical change (Walker, n.d.). However, subsequently published work produced by the research team has not mentioned the MLP (see: Devine-Wright, P., 2005; Walker, 2006; Walker et al, 2005; 2006). One explanation could point to problems with operationalising the MLP framework in practice. In any case the opportunity for more systematic and comprehensive analysis remains to be grasped. Another project within the STP, the study by Foxon and colleagues (Foxon et al, 2005; see also Foxon, 2003), offers a variation on the theme of the aforementioned possibility for future research. Here, Foxon et al

(2005) argue for the utility of taking a systemic approach to innovation process to inform policy-making to support innovation in sustainable technology. Further the researchers advance the argument for a stable and consistent policy environment and policy incentives to overcome system failure in establishing new and renewable energy sectors. For them, an 'innovation systems' approach requires different actors with distinctive roles to work together towards common goals in order to achieve transition; emphasis is placed on the development of a shared vision amongst (for example) government, industry, the public and the research community relevant for each sector. Arguably it could be even more interesting to consider the difficulties and adjustments to be confronted and made in reaching accommodations among actors, and the relevance of this to actions taken. This would lend the research a political dimension in tune with previous policy-related work invoking the concept of incrementalism (see Genus, 2006; Genus and Coles, 2005). Findings from a third project within the STP suggest that a number of factors at different 'levels' inhibit the diffusion of 'microgeneration' technologies - such as micro-combined heat and power, solar photovoltaics, and micro-wind turbines. These include overlong payback times and high costs, technical risks, and regulatory obstacles, and bounded rationality concerning, for example, a lack of reliable advice on the installation of the new technology (Watson et al, 2006). Here, as before, the designation of 'levels' could be the subject of inquiry in which research participants are asked to offer their own 'readings' of the processes of transition, which could be compared with the above.

Elsewhere, the study by Luiten et al (2006) emphasises the need for government policy towards R&D to be sensitive to the 'slowness' of energy efficient technologies, if it is to be effective in promoting their uptake, thus reinforcing the need for future research to address more effectively the incrementality of transitions. Again linked to issues of steering of transitions by state institutions, research in the future could embrace the approach taken by Weber and Hoogma (1998), in earlier work which deals with the style and dynamics of diffusion of combined heat and power and electric vehicles in five EU countries. Their specific topic of interest concerned how to go beyond prevailing concepts of national technological style, for example in order to understand better the role of the state in steering transition to environmental sustainability. In summary this research on micro-generation, which could be viewed as an emergent niche can also be seen to involve interlinked changes at all three 'levels' on a national scale, as well as to require international research co-operation over a range of different technologies. This certainly raises issues in utilising the MLP as it stands with poor boundary definition between levels, most significantly here relating to conceptualisation of the size and shape of the niche. The implications of this work for future research related to the MLP revolve around the need to take into account both 'macro level' system factors and niche-specific, actor- and technology-related characteristics. This is required in order to understand better how a style of policy-making which combines impulses for innovation at both structural and niche levels may be conducive to socio-technical change.

Here it is suggested that a focus on niche technologies which are in the process of development would be a useful application of the transition approach, allowing analysis of an unfolding transition path. For example the embedding or otherwise of technologies for the microgeneration of energy in society could be addressed in attending to a number of research objectives, such as:

(a). What factors at the 'landscape level' have influenced the promotion of niche technologies in society?

(b). How interactions and activities among various social groupings (at the 'regime level') combine to maintain incumbent technologies, or to enable the breakthrough and entrenchment of niche technologies through society?

(c). What constructions of 'user' are being employed in practice?

(d). What implications there are of these constructions of the 'user' for the policies, actions and values associated with technology development?

(e). What technologies and transition paths may be discerned related to the diffusion of technologies in specific contexts? To what extent do these paths constitute evolution, or radical transformation of existing regimes governing the use of technology?

(f). What models of sustainable technology development are employed by various actors in society? How do these compare with that of the MLP or the social construction of technology and with what implications for the categorisation of 'levels' and 'regimes' in the former?

Approaching the issue from these perspectives, it is suggested would serve to sharpen academic analysis of the conceptual base for the MLP.

4. Conclusion

The MLP represents an attempt at integration of the different strands of evolutionary innovation studies with the more sociological approach of technology studies in an attempt to bring together overlapping but disaggregated themes in the study of technological change. Thus far the paper has demonstrated the flexibility of the MLP for analysing technological transitions. In particular it appears that the adoption of the approach relies on the choices made by the analyst or researcher in presenting the insights gained from a detailed long-term case study. A fundamental criticism of research employing the MLP is that it is non-falsifiable, since additions and adaptations to the model can be made to accommodate any critique, and new transition paths can endlessly be added without threatening the basic structure. It is possible to transcend the limitations referred to above. Hence, flowing from the above, a number of suggestions have been made regarding future research on transition theory and MLP, which are restated in broad terms here. Firstly, it is suggested that researchers aim to assess the validity of the MLP to analyse emerging transitions based on the collection of primary data relating to contemporaneous socio-technical development. Research would seek to extend existing knowledge by applying more systematically than hitherto a (revised) multi-level framework of technological transition to analyse, for example, the complex of factors which seem to constrain or enable transformation and embedding of sustainable technology throughout society. Secondly, future research could in addition aim to consider the contribution and interaction of diverse groups at different analytic levels ('macro', 'meso' and 'micro') to socio-technical transformation or stability, while delineating in a more rigorous way or questioning boundaries between the suggested levels. An aspect of this is to consider how, the extent and in what circumstances state organisations and other interested or affected actors) affect the diffusion of technology through society. A related aspect would be to analyse behaviour of various protagonists and affected parties in technology development, in relation to various regimes and niches, which are said partly to characterise socio-technical systems. An additional concern could be to identify networks and interactions facilitative of or obstructive to transition. All of this would serve to complement the existing focus of transition theory/MLP research, which seeks to identify alternative transition paths and technology/ies in specific contexts. Overall, it should be noted that the criticisms presented in this article indicate that the conceptual framework of the MLP is not yet proven in its explanatory power beyond its usefulness as an analytical taxonomy. The research approaches identified here could strengthen the argument of supporters that the analysis of transitional technologies could make a significant contribution to the study of sustainable innovation, as well as clarifying the utility of the MLP.

Footnotes

1. See for example papers on: the transition from industrialised agriculture to organic farming in Switzerland 1970-2000 (Belz, 2004); from sailing ships to steamships in 19th century Great Britain (Geels, 2002); on water supply and personal hygiene in Netherlands 1850-1930 (Geels, 2005a);

from horse-drawn carriages to automobiles in the USA (Geels, 2005c; 2006d) and from propeller-piston engine aircraft to turbojets (Geels, 2006b); transformation of the Dutch highway system 1950-2000 (Geels, 2007); power generation through manure digestion and heat pumps in the Netherlands (Raven, 2004; Raven and Verbong, 2004a; 2004b); and from manual unloading and weighing of grain to floating pneumatic grain elevators in the port of Rotterdam during the early twentieth century (Van Driel and Schot, 2005). Van den Ende and Kemp (1999) do not use the multi-level framework as such to analyse 'regime shift' from digital computers to digital computing but rather analyse how a new technological regime grows out of an old one.

2. This is of particular concern for the study of ongoing radical innovations where a 'start point' may be difficult to identify without clear guiding characteristics. For example the difficulties in pinpointing a start to the transitional development of the fuel cell (Coles and Peters, 2003, Peters and Coles, 2006, Genus and Coles, 2003).

3. Carr (1961: 22) makes the following point: 'the facts of history never come to us 'pure' since they do not and can not exist in pure form: they are always refracted through the eyes of the researcher'. In addition Ladurie (1981) takes a sceptical view of historical research over the longer term, which gives an apparent stability to embedded routines and systems, although these might themselves could look like discontinuous change from a short term viewpoint i.e. the apparent stability of regimes in the MLP is a construct of the methodology used not an inherent property of the regimes under study.

References

Bell, M., Callon, M., Grupp, H., Kodama, F., Kuhlmann, S., Martin, B., Powell, W.W., Thomke, S., von Tunzelmann, N., 2007. Editorial. *Research Policy* 36, pp. 1-2.

Belz, F-M., 2004. A transition towards sustainability in the Swiss agri-food chain (1970-2000): using and improving the multi-level perspective, in: Elzen, B., Geels, F.W., Green, K. (Eds.), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*. Cheltenham: Edward Elgar, pp. 97-113.

Berkout, F., Smith, A., Stirling, A., 2004. Socio-technical regimes and transition contexts, in: Elzen, B., Geels, F.W., Green, K. (Eds.), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*. Cheltenham: Edward Elgar, pp. 48-75.

Bijker, W.E., 1987. The social construction of Bakelite: towards a theory of invention, in: Bijker, W.E., Hughes, T.P., Pinch, T.J. (Eds.) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press, pp.159-187.

Bijker, W.E., 1992. The social construction of fluorescent lighting or how an artefact was invented in its diffusion stage, in: Bijker, W.E., Law, J. (Eds.) *Shaping Technology Building Society: Studies in Sociotechnical Change*. Cambridge, MA: MIT Press, pp. 75-102.

Bijker, W.E., 1995. Sociohistorical technology studies, in: Jasanoff, S., Marsh, G.E., Petersen, J.C., Pinch, T. (Eds.) *Handbook of Science and Technology Studies*. Thousand Oaks: Sage, pp. 229-256.

Bijker, W.E., Hughes, T.P., Pinch, T.J. (Eds.), 1987. The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology, Cambridge, MA: MIT Press.

Brown, N., Michael, M., 2003. The sociology of expectations: retrospecting prospects and prospecting retrospects. *Technology Analysis and Strategic Management* 15, pp. 3-18.

Carr, E. H., 1961. *What is History?* Harmondsworth: Penguin.

Callon, M., 1987. Society in the making: the study of technology as a tool for sociological analysis, in: Bijker, W.E., Hughes, T.P., Pinch, T.J. (Eds.) *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. Cambridge, MA: MIT Press, pp. 83-103.

Coles, A-M, Peters, S., 2003. Sustainable development, global innovation and advanced technologies: the case of fuel cells. *International Journal of Environmental Technology Management* 3, pp. 278-289.

David, P., 1985. Clio and the economics of QWERTY. *American Economic Review* 75, pp. 332-337.

DEFRA (Department of Environment, Food and Rural Affairs), 2006. *Climate change – the UK programme* 2006. Norwich: The Stationery Office.

Devine-Wright, P., 2005. Local aspects of UK renewable energy development: exploring public beliefs and policy implications. *Local Environment* 10, pp. 57-69.

DTI (Department of Trade and Industry), 2003. *Energy White Paper, Our Energy Future – Creating a low Carbon Economy*. Cm 5761, Norwich: HMSO.

DTI (Department of Trade and Industry), 2006. *Our Energy Challenge: Power from the People*, DTI Microgeneration Strategy. London: DTI.

Foxon, T.J., 2003. Inducing Innovation for a Low-carbon Future: Drivers, Barriers and Policies. London: The Carbon Trust.

Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A., Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. *Energy Policy* 33, pp. 2123-2137.

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

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

Geels, F.W., 2005a. Co-evolution of technology and society: the transition in water supply and personal hygiene in the Netherlands (1850 – 1930) – a case study in multi-level perspective. *Technology in Society* 27, pp. 363-397.

Geels, F.W., 2005b. Processes and patterns in transitions and system innovations: refining the co-evolutionary multi-level perspective. *Technological Forecasting and Social Change* 72, pp. 681-696.

Geels, F.W., 2005c. The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860-1930). *Technology Analysis and Strategic Management* 17, pp. 445-476.

Geels, F.W., 2005d. Technological Transitions and Systems Innovations: a Co-evolutionary and Socio-technical Analysis. Cheltenham: Edward Elgar.

Geels F.W., 2006a. Analysing the breakthrough of rock 'n' roll (1930-1970): multi-regime interaction and reconfiguration in the multi-level perspective. *Technological Forecasting and Social Change*, article in press online at: **http://dx.doi.org.10.1016/j.techfore.2006.07.008**. (last accessed 21 November, 2006)

Geels, F.W., 2006b. Co-evolutionary and multi-level dynamics in transitions: the transformation of aviation systems and the shift from propeller to turbojet (1930-1970). *Technovation* 26, pp. 999-1016.

Geels, F.W., 2006c. The hygienic transition from cesspools to sewer systems (1840-1930): the dynamics of regime transformation. *Research Policy* 35, pp. 1069-1082.

Geels, F.W., 2006d. Major system change through stepwise reconfiguration: a multi-level analysis of the transformation of American factory production (1850-1930). *Technology in Society* 28, pp. 445-476.

Geels, F.W., 2007. Transformation of large technical systems: a multi-level analysis of the Dutch highway system (1950-2000). *Science, Technology and Human Values* 32, pp. 123-149.

Geels, F.W. and Raven, R., 2006. Non-linearity and expectations in niche development trajectories: ups and downs in Dutch biogas development (1973-2003). *Technology Analysis and Strategic Management* 18, pp. 375-392.

Geels, F.W., Schot, J., 2005. Taxonomy of Transition Pathways in socio-technical transitions. Paper given at 'Exploring Socio-Technical Transitions to Sustainability' Workshop, Institute of Commonwealth Studies, London, May 12.

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. *Research Policy* 36, pp. 399-417.

Geels, F.W., Smit, W.A., 2000. Lessons from failed technology futures: potholes in the road to the future, in: Brown, N. Rappert, B. Webster, A. (Eds.), *Contested Futures: A Sociology of Prospective Techno-science*. Aldershot: Ashgate Publishing, pp. 129-155.

Genus, A., 2006. Rethinking constructive technology assessment as democratic, reflective, discourse. *Technological Forecasting and Social Change* 73, pp. 13-26.

Genus, A., Coles, A-M, 2003. Systems of innovation, corporate innovation strategies and the promotion of Environmentally Sustainable Energy in the UK: The Case of Fuel Cells. What do we know about innovation? Conference in Honour of Keith Pavitt, Sussex, November 13-15.

Genus, A., Coles, A-M, 2005. On constructive technology assessment and limitations on public participation in technology assessment. *Technology Analysis and Strategic Management* 17, pp. 433-443.

Genus, A., Nor, M.A.M., 2007. **Bridging the digital divide in Malaysia: an empirical analysis of technological transformation and implications for e-development**. *Asia Pacific Business Review* 13, pp. 95-112.

Kemp, R., 1994. Technology and the transition to environmental sustainability: the problem of technological regime shifts. *Futures* 26, pp. 1023-1046.

Kemp, R. Rip, A., Schot, J., 2001. Constructing transition paths through the management of niches, in: Garud, R., Karnoe, P. (Eds.) *Path Dependency and Creation*. Lawrence Erlbaum, New Jersey, pp. 269-299.

Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology Analysis and Strategic Management* 10, pp. 175-195.

Ladurie, E. Le Roy, 1981. *The Mind and Method of the Historian*. Brighton: The Harvester Press.

Latour, B., 1988. Mixing humans and non-humans together: the sociology of a door closer. *Social Problems* 35, pp. 298-310.

Latour, B., 1991. Technology is society made durable, in: Law, J. (Ed.), *A Sociology of Monsters: Essays in Power, Technology and Domination*. London: Routledge, pp. 103-131.

Latour, B., 1999. *Pandora's Hope: Essays on the Reality of Science Studies*. Cambridge, MA: Harvard University Press.

Luiten, E., van Lente, H., Blok, K., 2006. Slow technologies and government intervention: energy efficiency in industrial process technologies. *Technovation* 26, pp. 1029-1044.

Monaghan, A., Steward, F., 2006. Introduction, in: Monaghan, A., Steward, F. (Eds.), Catalysing Innovation for Sustainability: Research Insights from the Economic and Social Research Council Sustainable Technologies Programme. London: ESRC, pp. i-iv.

Nelson, R.R., Winter, S.G., 1982. *An Evolutionary Theory of Economic Change*. Cambridge, MA: Belknap Press.

Peters, S., Coles, A., 2006. Strategic innovation in sustainable technology: the case of fuel cells for vehicles. *International Journal of Environment and Sustainable Development (IJESD)*: Special Issue: "Striving for Sustainability – Technologies, Businesses and Society" 5, pp. 338-354.

Phillimore, J., 2001. Schumpeter, Schumacher and the greening of technology. *Technology Analysis and Strategic Management* 13, pp. 23-37.

Raven, R., 2004. Implementation of manure digestion and co-combustion in the Dutch electricity regime: a multi-level analysis of market implementation in the Netherlands. *Energy Policy* 32, pp. 29-39.

Raven, R., Verbong, G., 2004a. Dung, sludge and landfill: biogas technology in the Netherlands, 1970-2000. *Technology and Culture* 45, pp. 519-539.

Raven, R., Verbong, G., 2004b. Ruling out innovations – technological regimes, rules and failures: the cases of heat pump power generation and bio-gas production in the Netherlands. *Innovation: Management, Policy and Practice* 6, pp. 178-198.

Rip, A., Misa, T.J., Schot, J., 1995. Constructive technology assessment: a new paradigm for managing technology in society, in: Rip, A., Misa, T.J., Schot, J. (Eds.*), Managing Technology in Society: the Approach of Constructive Technology Assessment*, London, Pinter, pp.1-12.

Rip, A., Kemp, R., 1998. Technological change, in: Rayner, S., Malone, E.J. (Eds.), *Human Choice and Climate Change, vol 2, Resources and Technology*. Battelle Press, Columbus, Ohio, pp. 327-399.

Rotmans, J., Kemp, R., van Asselt, M., 2001. More evolution than revolution: transition management in public policy. *Foresight* 3, pp. 15-31.

Schot, J., Rip, A., 1997. The past and future of constructive technology assessment. *Technological Forecasting and Social Change* 54, pp. 251-268.

Smith, A., 2006. Green niches in sustainable development: the case of organic food in the United Kingdom. *Environment and Planning C: Government and Policy* 24, pp. 439-445.

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

Steward, F., Coles, A-M, McNally, R., 2004. Technology transition as a process of innovation network reconfiguration. Paper presented at *Innovation Sustainability and Policy* conference, Kloster Seeon, May 23-25.

Steward, F., McNally, R., Coles, A-M, 2005. Seeing the wood for the trees – contested paths to environmental sustainability. Paper presented at *CESAGEN Genomics and Society* conference, London, April 12-14**.**

Steward, F. Tsoi, J.C.S., Coles, A-M, 2006. Nanoparticle innovation and print-on-paper fibre recyclability – mapping niches as emergent sociotechnical networks. *BRESE Working Paper, (06/20)*, available at: **http://www.brunel.ac.uk/about/acad/bbs/research/centres/brese/publications/wp** (last accessed 21 January, 2007).

Van den Ende, J., Kemp, R., 1999. Technological transformations in history: how the computer regime grew out of existing computing regimes. *Research Policy* 28, pp. 833-851.

van de Poel, I., 2000. On the role of outsiders in technical development. *Technology Analysis and Strategic Management* 12, pp. 383-397.

Van Driel, H., Schot, J., 2005. Radical innovation as a multilevel process: introducing floating grain elevators in the port of Rotterdam. *Technology and Culture* 46, pp. 51-76.

Verbong, G., Geels, F.W., 2007. The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system. *Energy Policy* 35, pp. 1025-1037.

Walker, G., n.d. Community renewable energy and sustainable transition management: analysis of policy change and institutional infrastructure. Powerpoint Presentation, available at **http://sustainable-cities.org.uk/database_files/Gordon%Walker.ppt** (last accessed 19 February, 2007, via Northumbria University website, http://northumbria.ac.uk/).

Walker, G., 2006. The ambivalence and complexity of sustainability. Paper presented to workshop on *Governance for Sustainable Development: Steering in the Context of Ambivalence, Uncertainty and Distributed Control*, Berlin, 6-7 February, available at **http://www.sozial-oekologische-forschung.org/_media/Walker_keynote_ambivalence.pdf** (last accessed 30 January 2007).

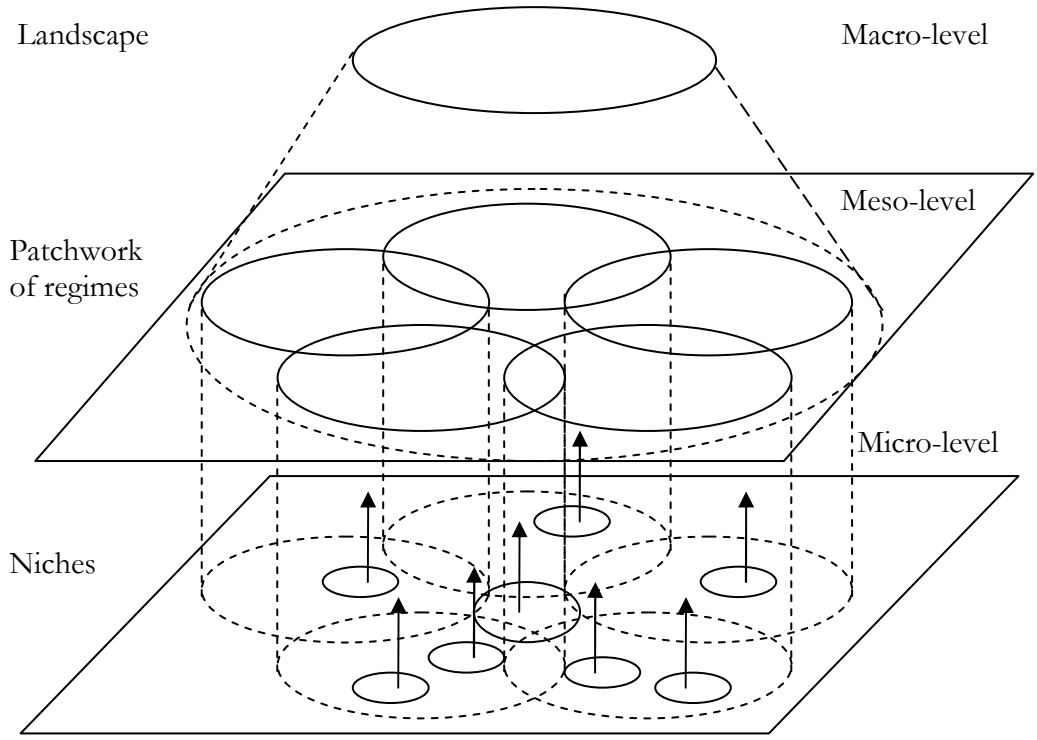
Walker, G., Fay, H., Devine-Wright, P., Hunter, S., Evans, B., 2005. Community and the embedding of sustainable technologies: drivers, meanings and policy. Powerpoint presentation given to ESRC Sustainable Technologies Programme meeting, Bakewell, July, available at: **http://geography.lancs.ac.uk/cei/downloads/stpjuly.ppt** (last accessed 19 February, 2007).

Walker, G., Devine-Wright, P., Evans, B., 2006. Embedding socio-technical innovation: an evaluation of community-based localism in renewable energy policy in the UK. Paper presented to *'The future of science, technology and innovation policy: linking research and practice'* conference, University of Sussex, September 11-13.

Watson, J., Sauter, R., Bahal, B., James, P., Myers, L., Wing R., 2006. Unlocking the Power House: Policy and System Change for Domestic Micro-generation in the UK. SPRU, Sussex.

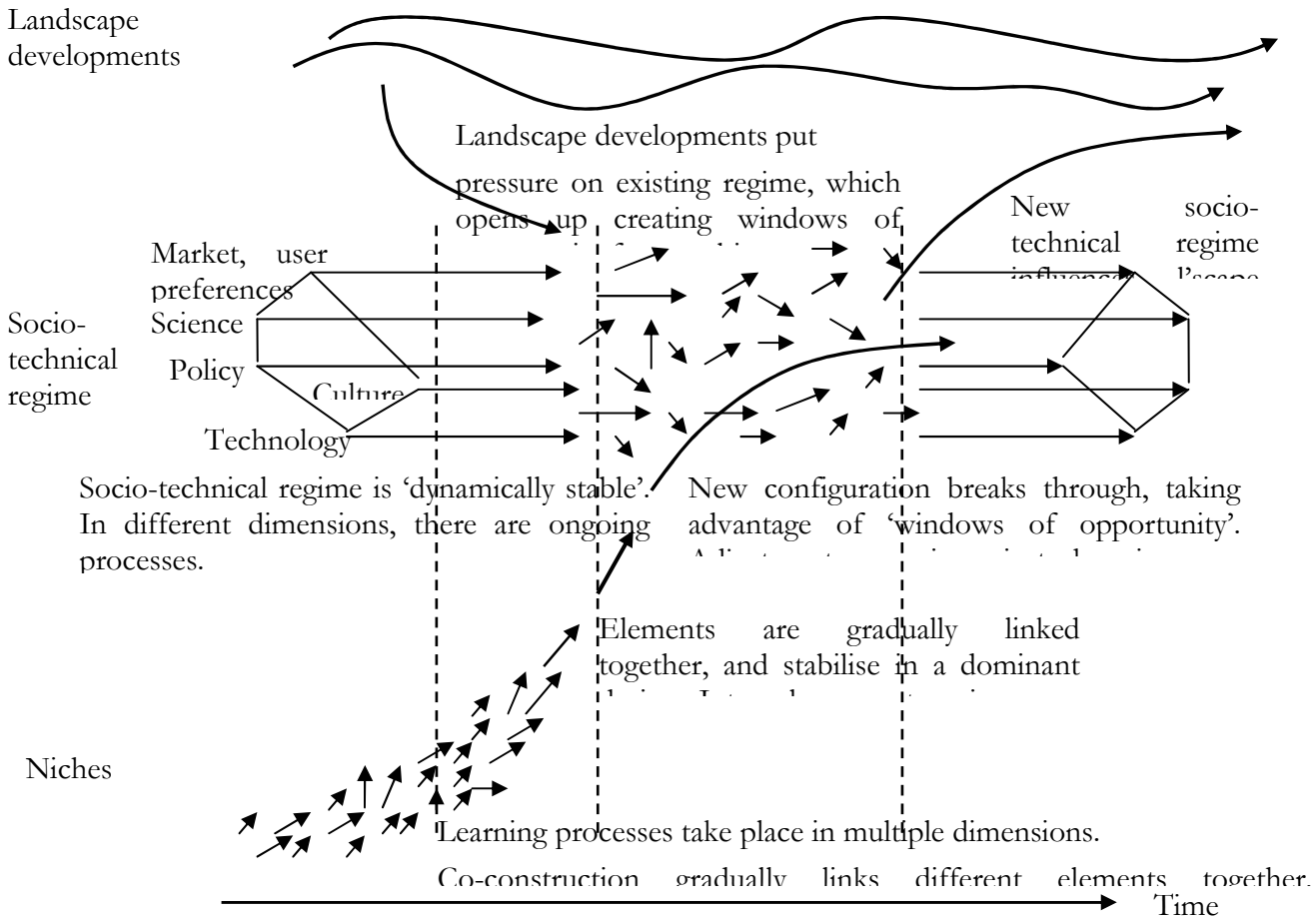
Weber, M., Hoogma, R., 1998. Beyond national and technological styles of innovation diffusion: a dynamic perspective on cases from the energy and transport sectors. *Technology Analysis and Strategic Management* 10, pp. 545-566.

Figure 1 Multi-level framework for the analysis of socio-technical transitions



Source: adapted from Geels (2002)

Figure 2: A dynamic multi-level perspective on system innovations



Adapted from Geels (2004).