The nature of transitions: Implications for the transition to a low carbon economy

A working paper by the Cambridge Institute for Sustainability Leadership

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Authors

Dr André Silveira, Postdoctoral Researcher, CISL

CISL's work on a Just Transition to a Low Carbon Economy is informed and guided by a cross-organisation working group: Lindsay Hooper, Mike Pierce, Louise Driffill, Tom Herbstein, Eliot Whittington, Kayla Friedman, and Nikki Bartlett.

Working papers

For general enquiries about the working paper please contact:

Communications Office
Email: info@cisl.cam.ac.uk

Abstract

This working paper is the second in a set of three working papers exploring the meaning of a ´just transition´ to a low carbon economy. Here an overview of theoretical approaches relevant to transitions is presented. Through the mapping of key interdisciplinary approaches on the topic, the paper aims to assist the management of transition processes, the assessment of its outcomes, as well as deliberative decision-making regarding the future of on-going transitions.

Seven bodies of academic literature are briefly reviewed. These are (i) the techno-economic approach; (ii) the socio-ecological transitions approach; (iii) the technological innovation systems approach; (iv) the multilevel perspective, which encompasses three approaches, namely strategic niche management, transition management, and reflexive governance; (v) the social practices approach; (vi) the resilience approach; (vii) and a human geography perspective, which explicitly considers aspects of social and environmental justice across space and time. Each can be critiqued for what it fails to incorporate, but the academic literature provides researchers, business leaders and policymakers with a range of often complementary lenses with which to assess current transitions and alternative futures. Considering this issue from a variety of perspectives may help to identify dimensions of the problem that may eventually be neglected or less scrutinised.

The paper concludes with an attempt to distil key messages from each strand of academic literature in a way that may provide business executives and policy leaders with new lines of enquiry and analysis when assessing current transition efforts and alternative paths, especially those that may lead us towards a more just transition to low carbon development.

1.Introduction

This working paper presents an overview of theoretical approaches relevant to transitions, and to the transition to a low carbon economy in particular. Given the wide spectrum of theories on transition and the need for tools to assess the most appropriate levers for change, this paper focuses primarily on those transition theories that relate to purposeful, target-oriented transitions. Theories addressing emergent processes of transition (eg those with no pre-set goal, deriving, for example, from new market opportunities) were not

considered unless literature regarded them as providing important lessons for targeted transitions.

This paper attempts to map the fundamental interdisciplinary approaches on the topic. It aims to assist the management transition processes and/or the assessment of its outcomes, and to provide ´thinking tools´ to leaders deliberating on what the nature of transition is or should be. When thinking of the justice of transition outcomes, this paper attempts to identify and understand the transition processes where just outcomes must be systematically sought.

This material may inform business and policy leaders involved in organisational and political debates on today's challenges associated with a just transition, and on the desired transition trajectory in the medium to long term. The paper may be useful to those participating in CISL's programmes of graduate study and executive education.

2. Methodology

This review was conducted in three steps:

i) A broad theory search, using search engines such as google scholar, University of Cambridge Library search engines, and the scopus database. Key words used were "transition theory", "transition management", "sustainability transitions", "environmental transitions", "energy transition"; "urban environmental transition". The same key words were used in google.com to locate useful grey literature.

ii) A narrowing-down step, in which theories considering historical evidence were selected (ie over at least one generation) in order to allow the identification of patterns of action and reaction that proved to determine the outcome of past transitions. Some of the empirical evidence, however, refers to shorter time spans - a decade in the case of the transition management strand.

iii) A final step to evaluate critiques of the theories and evidence. Multiple sources were cross-checked throughout the process to ensure that all relevant theories were assessed.

Research on transitions is a vast field, emerging from evolutionary economics and increasingly applied to ecological economics and sustainability transitions. The work on sustainability transitions has emerged at the end of the 1990s as a field of research in its own right. It has received an energetic push forward from a Dutch national research programme – the Knowledge Network for System Innovations and Transitions (2004–2009) – involving 12 Dutch universities and research institutes and three research groups from different schools of thought (Grin et al., 2011). The programme steered the creation of the international *Sustainability Transitions Research Network* (STRN, 2010), and set up its own journal (*Environmental Innovation and Societal Transitions)* in 2011. Four previously existing journals, including *Energy Policy*, *Technological Forecasting and Social Change* (TFSC), *Technology Analysis and Strategic Management* (TASM), and *Research Policy*, remain leading outlets for research findings in the field (Markard, 2012). The field of sustainability transitions is receiving increasing attention in the policy arena (OECD, 2011; UNEP, 2011), in

non-governmental organisations (eg IIED, 2012) and in social science research circles (eg STRN, 2010).

Research on sustainability transitions primarily addresses transformations in social and technological systems that are purposive and goal-oriented (Geels, 2011). Given the complex social, ecological and technological systems involved, these transitions have uncertain outcomes and require inclusive negotiations among public and business actors, civil society and consumer organisations with regards to their short- and long-term direction.

This increasingly well-established field of enquiry has not privileged any particular theory, approach or discipline. A wide range of social sciences are either actively engaged or in constructive dialogue with this field of research, including history, science and technology studies, sociology, evolutionary economics, political science and human geography. Substantial effort has been directed at gaining an in-depth understanding of historical processes of socio-technical transition. Case studies explored include transitions to pipe-based water supply (Geels, 2005a), electricity (Verbong and Geels, 2010), computers (Vand den Ende and Kemp, 1999), sewer systems (Söderholm, 2013), and automobiles (Geels, 2005b). Issues of power relations and political struggle are unavoidable and are thus an increasingly visible area of research.

3. Defining transitions in the context of sustainability

Sustainability challenges cross inter-related domains of human-environment interaction such as water supply, energy use and production, agriculture and transportation. In each of these domains, technology and infrastructure are tightly connected to user practices, life styles and social norms, as well as to business models, values, organisational and institutional structures, and policy processes.

Different strands of research on sustainability transitions emphasise different elements, but agree that transitions are about "long-term, multi-dimensional, and fundamental transformation processes through which the established socio-technical systems shift to more sustainable modes of production and consumption" (Markard, 2012, p.2). They involve far-reaching change in multiple inter-related regimes or domains of social life: technological; organisational; institutional; economic; political and socio-cultural. This fundamental change emerges from an alignment across these regimes, which, as shown in Figure 1, influence each other as time goes by (Geels, 2011). Transitions necessarily involve a wide range of actors and tend to unfold over long spans of time (ie one or two generations).
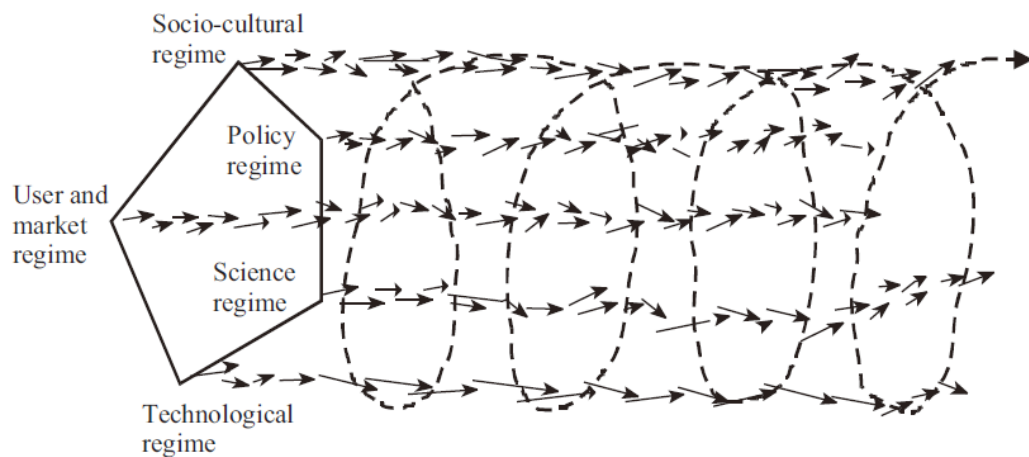
Figure 1 Alignment of ongoing processes in a socio-technical regime (reproduced from Geels, 2011, p.27)

Grin and colleagues (2010) present a typology of transitions, across three continua:

1. From emergent transitions that respond to perceived market opportunities (eg information and communication technologies) to targeted transitions that are guided by long-term goals (eg agricultural intensification);
2. From those that are loosely co-ordinated by national governments (eg pharmaceutical sector innovation) to transitions that are highly co-ordinated from the top (eg nuclear energy development); and
3. From transitions with a low-level social aggregation, covering one sector only (eg biomass energy supply) to high level of social aggregation encompassing the entire society (eg information and communication technology).

Figure 2 locates a series of different transitions within this typology, considering how they took place in the Dutch context:
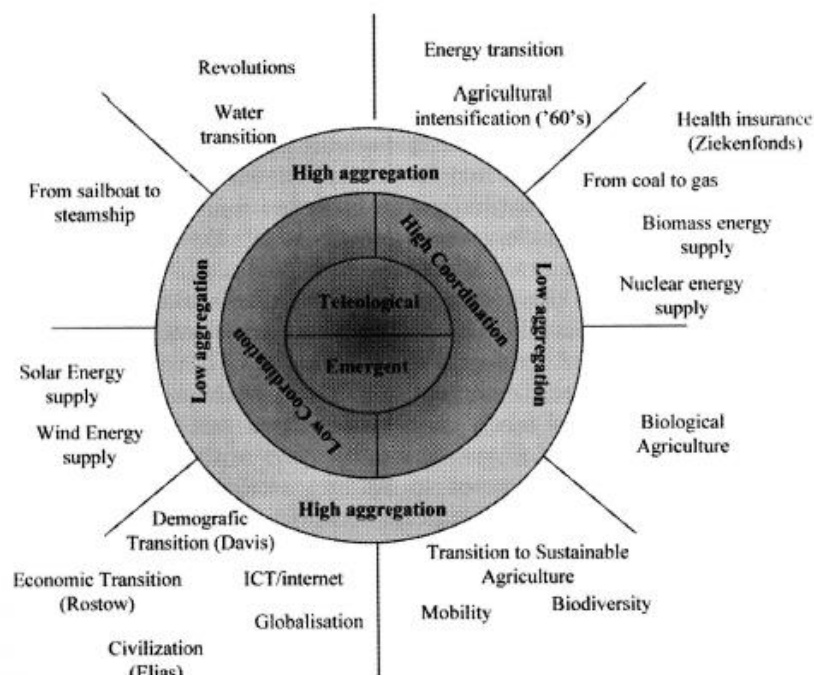
Figure 2 A typology of transitions with examples (Grin et al., 2010, p.112)

Inducing targeted, highly co-ordinated and socially aggregated regime transitions, such as the transition from coal to gas in the Dutch context (see Figure 2), requires new management and governance modes, informing the direction of the transition and setting the necessary long-term goals. Yet, setting a transition direction and associated goals is necessarily a contested and fundamentally political issue (Meadowcroft, 2011). What is considered 'sustainable' is a matter of debate and context, and should be a subject of research in itself.

4. Conceptual and theoretical approaches to the study of transitions

A wide variety of theoretical perspectives have been brought to bear on transition issues. The most relevant bodies of work are (i) the techno-economic approach; (ii) the socio-ecological transitions approach; (iii) the technological innovation system approach; (iv) the multilevel perspective, which includes strategic niche management and transition management; (v) the reflexive governance approach; (vi) the social practices approach; (vii) the resilience approach; (viii) and the human geography approach, which explicitly considers aspects of social and environmental justice across space and time. A simple description of these strands of thought, and some of their key strengths and weaknesses, are presented in Table 1 below. Click to see the table in large format.

				Based on the Multilevel Perspective (MLP)					
	The Techno-Economic Approach	Socio-Ecological Transitions Approach	Technological Innovation Systems	Historical co-evolution of social and technological systems	Active management of on-going transition processes	Reflexive governance	Social Practices	Resilience approach	Human Geography approach
Focus	Evolutionary economic theory (after Kondratieff / Schumpeter) — Long-term economic development cycles (40–60 years) — Clusters of new technologies	History of fundamental patterns of interaction between human society and natural systems — Social organisation of energy and material flows from and into the natural environment — Decoupling human development from resource consumption	Social and institutional conditions for the emergence of new technologies — Interplay between firms and other actors	Social and technological systems co-evolve through interaction between Micro level (niches), Meso level (regimes) and Macro level (landscape)			Everyday social practices — Consumer behaviour — Actor networks	Social-ecological systems as a complex adaptive systems characterised by uncertainty and non-linear feedback loops — Systematic learning approach to the way societies interact and manage the natural environment	Politics of environmental decision-making across space and time (incl. environmental justice) — Issues of social and ecological context
				Historical emergence of transition dynamics (not necessarily towards sustainability)	Recent and on-going processes of transition, with researchers active in the change process	Pervasive role of agency and power asymmetries — Issues of legitimacy for government/firms/science			
Findings	Explains how major technological change induces macro-economic cyclical movements, at national level — Identifies five techno-economic eras in last 250 years — Distinguishes different phases within an era — Incremental innovation is important to diffuse technology deriving from disruptive innovation	Gives consideration to the natural environment in macro-economic development through material flow analysis. — Transitions only occur when there is a structural change in a society's energy flows.	Identifies key processes that need to run smoothly for the innovation system to perform well — Pinpoints obstacles to radical technological innovation for sustainability	Patterns of change from below (niches) — Describes strategic niche management	Multiple sources and patterns of change and how they may be sequenced — Prescribes "transition management" as practice-oriented model (doing by learning/learning by doing)	Different ways in which power is present at the different levels — Insights on how strategic agency comes about	Innovation in social practices comes about through networks of people, circulating ideas, and notions of appropriate behaviour	Resilient social-ecological systems are characterised by adaptability and transformability at multiple scales of social organisation — Role of agents of change and their networks, working simultaneously at different spatial scales	Beyond national innovation — Interactions between regimes operating across multiple spatial scales (eg the influence of global forces in local decision processes) — Important to strengthen capabilities of local government authorities
Implications for a transition to renewable energy	Capability of the state is key to extend access of new energy production technology beyond elites	Technological innovation should target the provision renewable sources of energy	Government incentives to incumbent business actors are important for the emergence and consolidations of technological innovation hubs	Emergence of technology as a result of consumer demand, and then embedded in social practices	Energy transition steered towards a pre-defined goal by government actors and scientists (eg Dutch energy transition)	More inclusive and conscious decision processes, considering alternatives and sources of uncertainty	Changes in what is valued results in wholesome behavioural change (new consumption practices)	Emphasises the importance of social and institutional innovation in the management and governance of renewable energy	transition unfolds differently according to geographic context and spatial scale — Incentives need to be taylor-made and their impact closely monitored
Critique	Inability to identify causes behind long-wave cycles (eg over-deterministic view of macro-economic phenomena) — Not able to analyse processes of change at smaller scales of social organisation	Given its macro-economic focus, it does not consider the role of individual actors, belief systems, culture and political interests (such as those associated with fossil fuel production and consumption)	Marginalises cultural and social aspects of technology — Unable to understand why obstacles are there and therefore how to remove them — Excessive emphasis on large corporates and government actors	Does not consider all pressures of change	Little understanding of how problems are framed and how policy and research priorities are politically and socially constructed	Not reflexive enough about processes through which power imbalances are replicated — Neglects demand side actors such as consumers and social movements	May lose track of political and economic incentives and mechanisms behind circulation of ideas (eg government educational campaigns)	Weaker in the analysis of technological innovation issues — Difficulties in operationalising adaptability and transformability in different contexts — Does not fully explore the role of power asymmetries and how they may preclude adaptability and transformability	May not fully grasp obstacles for change within government and business organisations
				Insufficient understanding of the role of power and politics					
				Concept of "levels" leads the observer into hierarchical understanding of reality; insufficient attention to the role of actor networks spanning multiple spatial scales — Spatial bias towards national innovation					

4.1 The Techno-Economic Approach

Building on the work of economists such as Kondratieff (1935) and Schumpeter (1939), and notions like co-evolution and long-term development cycles, an evolutionary economic theory has emerged in the late 1980s to analyse trends and identify patterns throughout economic history (Freeman and Perez, 1988). The theory identifies long-wave development cycles, spanning periods between 40-60 years, which arise when clusters of new technologies become associated with new institutions and social behaviour, and disrupt the previous dominant paradigm. Focusing on economic development at the national level, the theory argues that major technological change induces macro-economic cyclical movements, brought about through a co-evolution between technology, science, economy, politics and culture (Köhler 2012).

Throughout the last 250 years, five techno-economic eras may be distinguished according to Perez (2002):

- Industrial revolution (1771–1829) in Britain; mechanisation of cotton industry, and highly improved water wheels that enhanced amount of power available. This was accompanied by infrastructure such as canals and waterways;
- Age of steam and railways (1830–1874) in Britain, spreading to continental Europe and USA; steam power and iron, applied in railways and steamships;
- Age of steel and electricity (1875–1908) Germany and USA overtake Britain; electricity and heavy engineering with steel;
- Age of oil, automobiles and mass production (from 1908) in USA, spreading to Europe and rest of the world; automobiles, aircraft, oil and petrochemicals, synthetic materials, mass production of an increasing range of consumer goods (ie Fordism);
- Age of information and telecommunications (from 1971), in USA, spreading to Europe, Asia and rest of the world; network computing, global digital communication, and cheap microelectronics, transform processes of production, consumption, distribution, financing and communication.

Andersen (2011) brings neo-Schumpeter's entrepreneurial theory of economic evolution to life by explaining the trickle-down effect of railroads in the context of regional innovation. He demonstrates that, even in this classical example of radical innovation, incremental innovation is important and has been used to increase the speed of technological diffusion.

Critics of this theory point out to its inability to identify causes behind long-wave cycles and its over-deterministic view of macro-economic phenomena. Given that it is not able to analyse processes of change at smaller scales of social organisation, it is deemed only interesting for large, long-living organisations such as multinationals, governmental organisations and multilateral institutions (Lachman, 2013). Still, Swilling and Annecke (2012) argue that this approach may enclose useful messages regarding the capabilities of the state for innovation and transition in both developed and developing countries.

Perez (2002) argues that each development cycle goes through 6 distinct periods:

a) an 'irruption phase' when innovations are generated;

b) a 'frenzy phase' phase when investors rush for a stake in the new business opportunities generated by those innovations;

c) the crowding-in of investments triggers a 'bubble burst', devaluation and financial crisis, which constitutes a critical turning point in the development cycle;

d) the state steps in to reorganise institutions, absorb new technologies, leading to a phase of 'synergy' and global dispersion of innovations;

e) a period of 'steady growth' sets in, with long-term profitability from dividends;

f) the cycle ends with a 'mature phase' during which the new technologies reach a saturation point, defined by stable production systems and diminishing returns of investment.

Swilling and Annecke (2012) note that "if state intervention during and after the crisis cannot restrain financial capital in order to clear the way for the more sedate and formalised investment modalities, the chances are that the benefits of the new technologies would be limited to the elites rather than dispersed across the whole economy and society" (p.12). The key to a successful development cycle lies, therefore, in a shift in the balance of power, away from actors thirsty for quick financial capital gains in favour of those with an appetite for long-term profit (Swilling and Annecke, 2012).

Key points

Major technological change induces macro-economic cyclical movements

In past transitions, the capability of the state to extend access to new technology was key

In countries where the state apparatus is unable to restrain speculative drives of financial capital, benefits of technological innovation tend to be captured by elites

Incremental innovation is important for the diffusion of disruptive innovation

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4.2. A Socio-Ecological Transitions Approach

An alternative and longer-term view of economic history is provided by experts at the Institute of Social Ecology based in Vienna, on the basis of the history of "specific fundamental patterns of interaction between human society and natural systems" (Fischer-Kowalski and Haberl, 2007). Human development takes place through the organisation of "energetic and material flows from and into its environment",[…]"transforming natural systems through labour and technology in specific ways to make them more useful for society's purposes. This in turn triggers intended and unintended changes in the natural environment to which societies react" (Fisher-Kowalski and Haberl, 2007, p. 14).

Authors in this 'school of thought' refer to three successive 'socio-ecological regimes': an initial hunter-gatherer regime; an agrarian regime (from approximately 13,000 years ago); and the current industrial regime that began 250 years ago. The method of 'material flow analysis' (MFA), popular among European ecological economists, is used to understand how material and energy flows *into and through* socio-ecological systems. A simple metric, named the 'metabolic rate', makes use of two indicators: tonnes of materials consumed per capita per annum, and energy used per capita measured in gigajoules (GJs). The MFA is able to specify the "feedbacks that transform both social and natural systems and the biophysical limitations of the systems involved" (Fisher-Kowalski and Haberl, 2007, p. 16).

Generally speaking, studies based on MFA analysis point out that transitions only occur when there is a structural change in a society's energy flows. Thus, in order to become more sustainable, economies must use less energy and materials while pursuing human development targets. For example, recent work in this strand of literature investigates ways in which worldwide re-industrialisation can be driven by innovations that 'dematerialise' economies, and decouple human development from resource consumption.

What sets this approach apart from others is the explicit consideration of nature in macro-economic development as well as in its methodology (ie MFA), which enables us to obtain empirical information about biophysical variables (Fischer-Kowalski, 2011). Although this approach is increasingly used in various practical and political contexts, it has also been criticised for its inability to provide concrete policy advice, and pinpoint where and when specific interventions need to be taken. In addition, its macro-economic focus does not consider the role of individual actors, belief systems, political interests and culture (Lachman, 2013).

On the basis of Charles Gore´s work with UNCTAD (2010), Swilling and Annecke (2012) use the socio-ecological approach in combination with the techno-economic one in an attempt to identify obstacles to be overcome for the next development cycle to emerge. According to Gore (2010), a long-wave cycle of development started in 1950 and ended with the global economic contraction of 2009. For the next cycle to emerge, technological innovation will need to provide renewable sources of energy, as advised by MFA analysis. Yet, it is argued that the necessary investments in new energy technologies have been neglected because of the 'political economy of oil' and the associated marginalisation of renewable sources of energy (Gore, 2010; Swilling and Annecke, 2012, p. 70).

Key points

Human development occurs through the organisation of energy and material flows from and into the natural environment

Transitions only occur when there is a structural change in a society's energy flows

Next development cycle can only occur if technological innovation radically enhances access to renewable sources of energy

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4.3. Technological Innovation Systems Approach

The technological innovation line of research hones in on the emergence of new technology and the institutional and organisational changes that have to go hand in hand with its development. The approach highlights the interaction between firms and other actors as the essential driver of technological innovation (Carlsson and Stankiewicz, 1991). This literature has primarily centred on national innovation systems (Freeman, 1988) and sectoral innovation systems (Hekkert et al., 2007).

Proponents see socio-technical systems as "focused on the development, diffusion and use of a particular technology (in terms of knowledge, product or both)" (Bergek et al., 2008, p.2). A recent refinement is the identification of key processes or functions that need to run smoothly for the system to perform well (Hekkert et al., 2007). This has been an attractive

approach for policy-makers, as it also pinpoints specific obstacles in transition processes such as insufficient knowledge diffusion and difficulties in gaining social, institutional and legislative acceptance (Lachman, 2013).

In the academic circles, the approach has been criticised for marginalising cultural and demand side issues; for being unable to theorise about why change happens, or why certain obstacles emerge; for placing excessive emphasis on large actors such as public entities and businesses, and for neglecting the role of individual leadership and social movements (Smith et al., 2010; Lachman, 2013).

An example of the deployment of this approach is the comparison done by Bergek and Jacobsson (2003) of the German, Dutch and Swedish wind turbine industries (see Markard, 2012). The technological innovation systems literature has been increasingly interested in radical, sustainability-oriented innovation with the potential to challenge established socio-technical systems (Markard and Truffer, 2008). In practice, when businesses consider technological innovation for sustainability, firms increasingly recognise that incremental change is not sufficient to achieve sustainability. Organisations like the Forum for the Future and Business in the Community (BITC) in the UK are supporting the business community in exploring notions of disruptive innovation (Forum for the Future, 2015) and breakthrough innovation (Forum for the Future, 2012).

In emerging markets, such as India, the concept of inclusive technological innovation is coming to the fore, both to assess processes as well as outcomes, for the benefit of the poorer (George et al., 2012). A related concept is that of 'frugal innovation' (Radjou et al., 2012), which is proving to have a disruptive and transformational role in emerging markets and more recently in developed markets (Immelt et al., 2009). Some are already investigating how this type of innovation can provide sustainable, carbon neutral energy for all (Nocera, 2012).

Key points

Technological innovation is determined by firms and their interaction with other organisations (in both the public and private sector)

Technological innovation goes hand in hand with institutional and organisational change

While the approach helps identify drivers and constraints to radical technological innovation, it is less helpful to understand how positive change can be achieved and obstacles overcome

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4.4. The Multi-level Perspective

A multi-layered way of thinking guides a large and growing literature on sustainability transitions, as researchers consider different speeds of change at different levels of social life. A Multi-level perspective (MLP) theory was first presented in Geels (2002) to deepen the understanding of long-term historical transition processes of sectoral systems of innovation, such as those from sailing ships to steamships. These innovation systems were reconceptualised as socio-technological regimes, which refer mainly to an interconnected set of formal and informal rules or institutional structures (Grin et al., 2011). Geels approach synthesizes notions of evolution from the literature of evolutionary economics

(Freeman and Perez, 1988), and expands the literature on science and technology studies (Latour, 1991, 1993; Law and Callon, 1992) in order to analyse long-term, large-scale technological developments (Geels, 2002). Later work by Geels (2004) incorporates social theory more explicitly into the MLP, on the basis of Scott (1995) and his distinction between regulative (ie laws and regulations), normative (ie values and norms) and cognitive rules (ie beliefs and taken-for-granted knowledge).

MLP sees transitions as the result of the interaction between micro, meso and macro levels of individual agency and rule making. For example fast change in social practices at micro-scales of action (eg in in an organisation), slower change of institutionalised practices at the meso-scale of regimes (eg in a sector), and a slow changing macro-scale of background social and environment (long-term background processes such as economic globalisation and climate change). These are conceptualised as the *niche*, *regime* and *landscape* levels respectively. Here levels do not relate to spatial scales of social organisation (eg local, national and international) but to the context in which individuals interact with the rules that guide their behaviour.

The concept of socio-technical *regime* receives particular attention. It refers to knowledge, engineering practices and technological innovations that are deeply intertwined with social expectations, skills of users, supporting infrastructure, as well as institutional structures (such as rules and regulations) (Markard, 2012). Innovation occurs as a result of co-evolution between sub-regimes associated with the domains of science, technology, politics, markets, user preferences and cultural meanings. Dynamics of stability and change correspond to alignment and tension between sub-regimes (Geels, 2002, 2011). When regimes become well-established, they impose a specific logic and direction for gradual socio-technical change, along a certain path of socio-economic development. The literature refers to this as "path-dependence" or the "lock-in" effect (Geels, 2011). *Niches* may be conceptualised as "protected spaces" or "demonstration projects", where radical technological innovation emerges without selection pressure from the prevailing regime (Geels, 2011). The socio-technical *landscape* refers to the external context that actors at niche and regime levels cannot influence in the short run, such as demographic trends, political ideologies, societal values, macro-economic patterns, and climatic conditions. Figure 3 depicts how landscapes, regimes and niche innovations can influence one another.
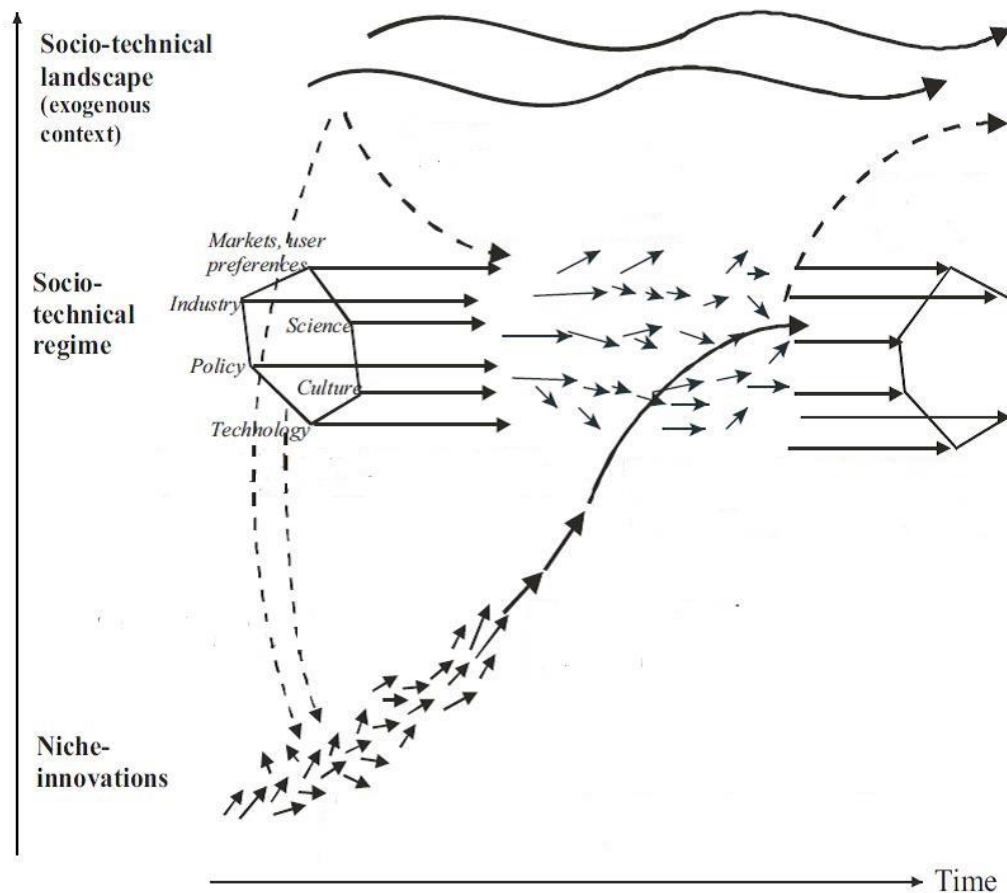
Figure 3 Multi-level perspective on transitions (reproduced from Geels, 2011, p.28)

Applying this thinking, transitions are shifts from one socio-technical regime to another. They are rare and special cases of long-term development, that result from co-evolutions among heterogeneous actors active at niche, regime and landscape levels. Two different research strands using MLP have identified different historical patterns and mechanisms of transition, and on this basis propose different strategies when promoting sustainability transitions (Grin et al., 2010).

a. Strategic Niche Management

One MLP research strand proposes Strategic Niche Management (SNM) or the deliberate creation and support of socio-technological niches as a way to trigger regime shifts (Kemp et al., 1998). Research on SNM encompasses two different foci: a) internal niche processes; and b) SNM and the interaction of niches with socio-technical regimes and landscapes (Grin et al., 2010). Niches gain strength when multiple learning processes produce a stable configuration of practices, and when networks become larger and include powerful actors that convey legitimacy and resources. Through processes of social learning, niche innovations gain momentum and may compete with established technologies. Technologies are seen as socially embedded (Grin et al., 2010).This strand has identified historical patterns of niche-regime-landscape interactions that have constituted pathways to transition. Table 2 presents them in summary form, with historical examples.

Table 2: Examples of historical patterns of niche-regime-landscape interactions

Pattern	Description	Historical evidence
Reorientation	If there is moderate pressure from landscape level but niche innovations are not sufficiently developed, then actors in the established regime will adjust the direction of development.	Transition from cesspools to sewer systems in the Netherlands from the 1850-1930 (Geels, 2006a).
De-alignment and re-alignment	In the face of large scale pressure at landscape level, regime coherence is eroded. Multiple niche innovations co-exist and compete. Over time one becomes dominant and is successful in creating a new regime.	Transition from horse carriages to automobiles in the USA from 1870-1930 (Geels, 2005).
Substitution	Strong pressure from landscape level at a time when niche innovations are sufficiently developed. Dominant niche breaks through and substitutes existing socio-technical regime.	The UK's transition from sailing ships to steamships in the 19th century (Geels, 2002).
Reconfiguration	Regime level adopts niche innovations to solve some local problems (experimentation). These trigger further adjustments in the configuration of the socio-technical system.	Transitions from traditional factories to mass production in the USA (Geels, 2006b).

The SNM strand of transition studies has branched out to consider inputs from historical patterns of social change in non-technological contexts, such as patterns of political revolution where bottom-up and top-down change processes co-exist (see Sztompka, 1993). Dahle (2007) builds on this literature and outlines four strategic profiles of agents of change in sustainability transitions, namely *the reformists* (political and business elites that decide to enact change into greener directions); the *impatient revolutionaries* (when new elites with deeper environmental awareness come to power and are willing to take drastic measures); *patient revolutionaries* (green niche alternative proponents that wait for a 'window of opportunity' and actively facilitate environmental innovation, public education and awareness raising); and *grassroot fighters* (change comes from social movements acting outside existing institutions).

The literature on transitions to democracy may hold further interesting insights (Adler and Webster, 1995; Habib et al., 1998; Guo, 1999), as may the literature on transitions from planned to market economies (Cao and Nee, 2000). The first stresses the dynamic power struggles between incumbent and emerging elites, and how these found themselves inter-connected with key social movements, and global sources of political pressure. The case of South Africa has received particular attention in this regard (eg Adler and Webster, 1995; Habbib et al., 1998). The second stresses aspects of conversion of political power to economic power within incumbent elites, and derives conclusions from cases such as China.

More contemporary studies of socio-technical transitions explain the ups and downs of 'green' niche innovations by analyzing the learning processes, network dynamics, and struggles against existing regimes on multiple dimensions. These include literature on electricity systems (Verbong and Geels, 2007, 2010; Hofman and Elzen, 2010); mobility and 'green' cars (Nykvist and Whitmarsh, 2008; Van Bree et al., 2010; Geels et al., 2011); biogas

and co-combustion (Raven, 2004); organic food and sustainable housing (Smith, 2007); and animal welfare in pig farming (Elzen et al., 2011).

Key points

Regime shifts can be promoted by deliberate creation and support of strategic niches

Niches gain strength when parallel learning processes produce a stable set of practices (ie the use of the new technology becomes socially embedded)

Regime shift happens when networks of actors supporting the niche includes powerful incumbent actors

The strategic behaviour of individual actors plays a crucial role

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b. Transition Management

A second research strand based on MLP theory focuses on transition management and combines work on technological transitions with insights from complex systems theory and governance (Grin et al., 2010). This approach has received attention from the OECD and its Technology and Innovation Policy Group, who see transition management approaches as complementary to the innovation systems approach commonly used by the group. Transition are seen as fundamental change in structures (physical, economic, institutional), social practice and culture. The OECD (2003) explores the deployment of this approach by the Dutch government in transitions processes related to energy, agriculture and transport, and extrapolates lessons for low-emission energy supply systems.

This key theoretical approach has not been sufficiently corroborated by historical evidence but was considered key to this review as the main research strand concerned with targeted transitions. Researchers in this line of enquiry identify and analyse patterns of niche-regime-landscape interaction such as pre-development, take-off, acceleration and stabilisation (Rotmans et al., 2001; Schneider, 2003) as explained in Table 3.

Proponents of transition management have proposed and applied an instrumental, practice-oriented model for influencing ongoing transitions in more sustainable directions (Loorbach, 2010). This line of work puts forward a prescriptive strategy, applied in various regional and national policy projects. Researchers participated in problem framing exercises in multi-stakeholder processes, implementing agendas in experiments, while evaluating and monitoring the process (Schneider, 2003). The approach privileges a learning-by-doing and doing-by-learning approach. Yet, the national policy results of these processes remain to be assessed (Markard, 2012).

Table 3 Patterns of niche-regime-landscape interaction (Schneider, 2003, p.12)	
Pre-development phase	The regime acts as an inhibiting factor. Dominant actors seek to maintain social norms and belief systems, and improve existing technologies in order to prevent threatening developments.
Take-off phase	Developments at micro and macro scale align and put pressure on the regime.

| Acceleration phase | The regime plays an enabling role, providing capital for innovation, as a result of self-examination and/or pressure from the micro or macro-level. |
| Stabilisation phase | Acceleration process slows down given that a new regime is in place and starts to resist new development. A new dynamic equilibrium is in place, which may accommodate the seeds of another transition process. |

Key points

The effectiveness of targeted transitions depends on effective links between policy makers, scientists and stakeholders at national level

It is crucial to remain practice-oriented (ie learning by doing /doing by learning) in face of complex problems

Transition is made possible through a combination of changes in macro level structures (both physical and institutional) and changes in social norms and practices at micro level

c. The Critiques levied at MLP Theory

A set of critiques have been levied at MLP theory and its research strands, from different perspectives. These are summarised in Table 4 in order to aid the subsequent review of bodies of research informed by these critiques.

Geels (2011) responds directly to most of these critiques, suggesting that MLP is being strengthened by addressing critical views and by incorporating improvements suggested by authors from different disciplinary backgrounds. The mildest critique comes from proponents of an innovation systems approach – who are actively building bridges to enable translation of results between the two approaches (Markard, 2008). The critiques that seem furthest from the original MLP literature are those leveraged by:

   i)   political scientists: calling for deeper theorisation of the role of power, politics and contestation;
   i)   sociologists: proposing the alternative use of theories of social practice; and
   ii)   human geographers: considering human-environment interactions at multiple spatial scales, political economy pressures across space and time, and ways in which the social construction of space influences environmental outcomes.

Table 4: Key critiques to MLP-based research	
(a) Lack of agency	
Smith et al. (2005)	• "too descriptive and structural" • insufficient analysis of agency and the role of power and politics
Genus and Coles (2008)	• not incorporating approaches that deconstruct problem frames (constructivist) • ignoring actors with alternative problem frames

Freitas (2015)	• not considering political and ideological aspects embedded in the various transition patterns • not addressing implications for social equity and poverty alleviation
(b) Operationalisation of regimes	
Berkhout et al. (2004)	• unclear how the concept should be operationalised and applied in empirical research
Genus and Coles (2008)	• tendency to reify regimes, presenting as homogeneous entities with intentionality
(c) Bias towards bottom-up change models	
Berkhout et al. (2004)	• MLP privileges processes of change that begin within niches and work upwards (regimes are framed as barriers to overcome); at the expense of pressures deriving from regime or even landscape levels
(d) Explanatory style (what counts as valid explanation is flawed)	
Genus and Coles (2008)	• MLP contribution limited to offering a model to interpret experience
(e) Methodology	
Genus and Coles (2008) Geels (2011)	• use of second-hand interpretations of historical processes • mostly exploratory studies based on one case study
(f) Misleading hierarchies vs flat ontologies	
Shove and Walker (2010)	• use of hierarchic notions is misleading and makes analysts blind to the pervasive role of actor networks that span multiple spatial scales
(g) Geographic bias	
Markard (2012) Lachman (2013)	• strong European bias in case study selection (22% of papers deal with NL, UK and DE) with little research on non-OECD countries. • bias toward research at national level with global, regional and urban analysis being much less frequent

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Key points

It is important to seek a better understanding of embedded power asymmetries and how they relate to the framing of problems and the setting of political agendas within a regime

Incumbent regimes are not homogeneous and contain internal contradictions

Politics play the decisive role in setting a transition trajectory

Actor networks working across multiple spatial scales can work to consolidate social norms, social practices and political power

The implications of the transition for social equity should be openly discussed

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4.5. The Reflexive Governance Approach (a Political Science Perspective)

A reflexive governance approach has been articulated by Grin et al. (2010), partly in order to address the criticism levied by political scientists and improve the frame of analysis

emerging from the MLP. It is concerned with the cross-cutting issue of agency in transitions, exploring the role of politics and power relations, and problems of empowerment and legitimisation. Agency plays a role in episodes of change in that social actors can influence how, and how fast, a transition may occur. Actors can also create windows of opportunity or exploit opportunities created by pressures at meso or macro scale. Grin et al. (2010) consider different types of power at different levels of structuration, as shown in Table 5.

The reflexive governance approach goes beyond a view that agency is naturally limited by the current regime, or the limited powers and competences of any individual actor. It assumes that multiple agents seek to influence transition, and focuses research on whether actors hold sufficient competence for strategic agency, and whether they are able to connect and increase their influence and social power. A transition towards sustainability is but one possible outcome of changes, from alignments and re-alignments of actors in the realm of market, government, science and technology, and civil society.

Table 5: Types of power at different levels of structuration (Grin et al., 2010)

Level	Type of Power	Description
Niche	Relational	Outcomes achieved by agents in interaction; agents have different competencies and abilities
Regime	Dispositional	Rules, resources and dominant actor configurations favour certain practices and perceptions of problems
Landscape	Structural	Higher level concepts that structure ways of thinking about is considered to be a "normal" and legitimate (re)action

According to this approach, transitions literature is focusing too much on corporate, technology and policy actors, while actors such as consumers and others representing the demand side are neglected (Grin et al., 2010). In addition, a call for further research on community-based initiatives and their use of local knowledge is made on the basis that successful transitions utilise both formal expertise and local, lay knowledge (see Seyfang and Smith, 2007).

Key points

Current transition processes cannot be understood without detailed analysis of individual agency and processes of empowerment and legitimisation

Individual actors and their networks can influence how, and how fast, a transition occurs

Efforts to transition to a low carbon economy must go beyond corporate and policy actors, to consider the views and priorities of consumers, civil society organisations and local communities

The knowledge used to guide transitions should go beyond formal expert knowledge to include local lay knowledge

4.6. The Social Practices Approach (the Sociological Perspective)

Novel sociological approaches, studying consumer/user behaviour and social practices (Shove and Walker, 2010), address some of the key shortcomings in the transitions literature, namely its lack of attention to the role of actor networks and the diffusion of behavioural norms. This is also a response to MLP's neglect of consumers themselves and how knowledge and innovation is circulated and appropriated by consumers.

This line of research argues that social practices are a key unit of analysis (Spaargaren, 2011). Spaargaren (2003) proposes a new approach for the study of consumer behaviour, refocusing the attention on everyday routines and shared social practices related to food, energy, mobility, and tourism.

Shove and Walker (2010) have taken this agenda forward and researched the demise of the practice of weekly showering in the UK, and social practices behind traffic flows in the city of London. The first may be seen as an emergent innovation, while the second includes more deliberate interventions such as the creation of the congestion zone. Shove and Walker (2010) conclude that effective innovation in social practices goes beyond the promotion and adoption of technology; or the enrolment of users. They emphasise the importance of circulating diverse elements of practice (practical know-how; concrete physical activities; new meanings, ideas and understandings) reproduced across space in a fluid, non-hierarchical manner.

A related research strand emerges from a purely science technology studies perspective. It investigates actor-networks in "arenas of development" (a concept parallel to that of socio-technical regimes). The "arena" is a space and place of interaction between human and non-human elements that seem distant in geographical and cultural terms (Joergensen, 2012). Non-human entities include technologies, institutions, visions and practices. As human and non-human elements become tightly inter-connected and form actor-networks, they gain meaning, position and identity. Alignments between actor-networks become temporarily stable in so-called "actor worlds". Ample space is left in this approach for the possibility of tensions and inconsistences within "arenas". By contrast, MLP-based approaches tend not to include misaligned actors enrolled in competing "actor worlds" or who perform practices that are not normalised or rule-following (Joergensen, 2012).

Key points

The transformation of social practices is a crucial part of any transition

Actor networks play a key role in the circulation and diffusion of new practices

When studying current energy transitions, it is fundamental to study consumer behaviour, everyday routines and shared social practices

Within any given regime, there are misaligned actors who rely on alternative technologies, institutions, visions and practices. These actors may spur innovation and support a transition

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4.7. The Resilience Approach

Resilience scholars are now also engaging directly with the literature on sustainability transitions (Olsson et al., 2014). They criticise theories of socio-technological transitions based on MLP on account of their inadequate consideration of ecological systems, taken as background variables at the landscape level. 'Resilience thinking' focuses on social-ecological systems as a complex adaptive systems characterised by uncertainty and non-linear feedback loops, and builds on Holling's (1996) conception of ecological resilience. Contrasting with the engineering view of resilience that emphasizes persistence, social-ecological resilience demands societies to adopt a systematic learning approach to the way they interact and manage the natural environment (Olsson et al., 2014). Human societies cannot afford to undergo major social and technological transformation without improving their capacity to learn from, respond to, and manage feedbacks from dynamic ecological systems.

Resilient social-ecological systems, the normative goal in this literature, are characterised by adaptability (ie the capacity to deal with change while staying within a given dynamic equilibrium, or pathway of change) as well as transformability (ie the capacity to enable fundamental change from one pathway to another, forming a new equilibrium) (Folke et al., 2010) at multiple scales of social organisation. Transformation in social-ecological systems takes place in three stages: (1) preparing for transformation, (2) navigating the transition, and (3) building resilience of the new direction (Olsson et al, 2014). The initial stages of transformation depend on the existence of a window of opportunity, which may be emergent or induced. Research under this approach highlights the role of agents of change and their networks, working simultaneously at different spatial scales. In the first stage, actors and their networks use their presence and influence at multiple scales to open up new trajectories of development, and create new opportunities. In the navigation phase, actors operating across scales bridge actors in different scales, contributing to the identification of important alternative innovations, launching new initiatives and attempting to scale up selected innovations. In the third stage, new incentives as well as values of stewardship contribute to reinforce a new pathway of development.

This approach stresses the importance of social and institutional innovation in systems of environmental management and governance, and may be criticised for failing to integrate technological innovation explicitly in its analysis. One technical innovation that seems to be more extensively considered is the role of social media and open source software in promoting systematic learning, sharing of information, experimentation and decentralised innovation (Westley et al., 2011).

However, this line of thinking usefully highlights that technology may be a double-edged sword when it comes to wholesale transformations towards sustainability. There is a

possibility that technological innovation may drive human development in directions that are opposed to sustainability (van der Leeuw, 2010) and reinforce inequalities and relations of domination in human society (Olsson et al. 2014). An example commonly given by scholars in this approach is the ongoing and increasingly global adoption of biofuels, as a substitute for oil. Biofuel may contribute to slow down climate change but it has been shown to lead to destructive land-use change and biodiversity loss (Grau and Aide, 2008; Westley et al. 2011; Olsson et al., 2014). This strand of research, argues that an understanding of the interconnected nature of social, technological, and ecological systems is crucial for the prevention of undesirable and unintended outcomes of initiatives aiming to enhance sustainability.

The key recommendation is that of systematic learning and inclusive experimentation and innovation in order to broaden the diversity of options, ideas, institutional solutions, organisational strategies and practices in relation to social-ecological systems and conservation of ecosystem services (Cummings et al., 2013).

Key points

In order to enhance their resilience, organisations should adopt a systematic learning approach to the way in which they use and manage the natural environment

Transitions rely on the capabilities of actors and organisations to adapt to change and to enact fundamental change;

These capabilities rely upon individual actors and their networks working across scales of social organisation

There is a possibility that technological innovation may drive development in directions that are opposed to sustainability and reinforce inequalities in society

Transitions depend upon social and institutional innovation, oriented towards learning and experimentation

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4.8 The Human Geography perspective

Reviews of sustainability transitions literature demonstrate a geographic bias within it (Markard, 2012; Raven et al., 2012; Lachman, 2013). The predominant focus has been the national level, neglecting analysis of global, regional and urban scope. Moreover, there is also a strong European bias in case study selection and little research on non-OECD countries. More substantially, existing literature fails to contextualise transition processes spatially, overlooking four important points. First, it fails to acknowledge how institutions are embedded in specific spaces, places and territories, and second it overlooks the geographic unevenness of transition processes (Coenen et al., 2012). Third, it does not consider the extent to which innovative technologies are adapted to specific geographic and institutional contexts. Fourth, it overlooks the relation between local innovation networks and the global diffusion of socio-technical regimes (Markard et al., 2012). These are obstacles when considering the potential and constraints of transferring any form of innovation from one context to another (Lachman, 2013).

Examples of work addressing these gaps include Bulkeley and colleagues (2011) who investigate the role of cities, and global networks of cities, in low carbon transitions. This research builds on the understanding that key aspects of technology, innovation and competitiveness are no longer an exclusively national concern, but are also being transferred to cities. With an explicitly multi-scalar approach, Raven and colleagues (2012) present a case study on biogas in India, with insights into the ways local innovation niches are connected with global resource and knowledge networks. Raven and colleagues (2012) explore a new version of MLP infused with an explicit approach to space and spatial scale. Their paper is part of a body of new work in non-OECD contexts, particularly in Asia.

In a special issue on sustainability transitions in Asia, Berkhout and colleagues (2009) apply ideas of systems innovation derived from the MLP approach to analyse the emergence of new and more resource-efficient socio-technical systems in developing Asia, in the context of the interaction between domestic and globalised markets, knowledge flows and governance mechanisms. In the same special issue, Angel and Clark (2009) discuss sustainability transitions in the newly industrialising countries of East Asia, including China. They canvass differences in the extent to which countries have taken on regulatory practices originating in OECD countries; and, more substantially, a variety of policy and institutional innovations that promise to provide new paths of industrialisation and urbanisation that are less polluting and energy-intensive.

With a specifically urban focus, the work of McGranahan and colleagues (2001) on 'urban environmental transition theory' remains an essential reference. They theorise that urban environmental burdens tend to change according to a specific pattern as cities develop and become wealthier. Following urban development, environmental challenges tend to become more dispersed and less immediately visible. In low income cities, environmental challenges are localised, immediate and health threatening; while in wealthier cities they are increasingly global, intergenerational and ecosystem threatening (McGranahan et al, 2001). Empirical evidence emerges from cities such as Accra (Ghana), São Paulo (Brazil), and Jakarta (Indonesia) (Marcotullio and Lee, 2003). The Marcotullio and Lee (2003) study compares US and Asian cities, which they note have undergone more rapid and compressed forms of transition. National and local conditions and globalisation forces have worked in tandem to quicken the pace of urban environmental transition in Asian cities, and compress the stages of transition (Marcotullio and Lee, 2003). They suggest the challenges of rapidly changing Asian cities call for organic, innovative policies.

McGranahan (2007) emphasises the importance of understanding the spatial dimensions of urban environmental problems when addressing environmental justice issues, particularly the issue of differentiated capacity to deal with environmental burdens. The author identifies a pattern of displacement of environmental burdens away from affluent neighbourhoods, and retention in deprived neighbourhoods or settlements. This trend is placing a disproportionate burden, felt worldwide, on disadvantaged groups such as urban slum dwellers, as investigated recently in the emerging economies of the BRICS (Brazil, Russia, India, China and South Africa) (McGranahan, 2012).

A particular branch of human geography – that of political ecology – proposes particularly apt analytical tools to address issues of justice in socio-technical transitions to sustainability. Lawhon and Murphy (2012) usefully present, on the basis of a case study on the diffusion of GM crops, the overlap between political ecology and sustainability transitions literature.

The authors suggest practical ways to factor in asymmetric power relations, and engage with the inevitably political nature of environmental decision-making. These include considering how knowledge is constructed (both scientific and lay knowledge), and questioning transition processes led primarily by policy-makers, scientists and large, well-resourced firms. Issues typically investigated in political ecology include: who is represented and included in decision-making processes? Where and at what scale are decisions made? Whose knowledge counts and why? Who are the main winners and losers in those decisions? What are the social and ecological consequences of the adoption of certain technologies? The political ecology discipline is particularly well known for its engagement with the so-called Global South. It may thus hold insights into societies where the role of policy-makers, public managers and elite scientists (arguably central to sustainability transitions in the "Global North") are less significant.

Lawhon and Murphy (2012, p.371) argue that political ecology can help explain why transition processes occur unevenly across space, and contextualise factors driving or constraining regime changes in relation to particular scales and "space-time contexts".

Key points

It is important to consider how a transition process occurs differently in different on spatial contexts (eg global, national, regional, urban, rural)

Successful innovations are those that emerge from, and therefore are well adapted to, specific geographic and institutional contexts

The outcomes of transitions are geographically uneven, and thus issues of social and environmental justice must be systematically analysed

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5. Conclusion

The volume and breadth of issues dealt with in the literature on transitions is considerable. A wide range of theoretical approaches exists to analyse important aspects of the transition to a low carbon economy. Each can be critiqued for what it fails to incorporate, but the academic literature provides researchers, business leaders and policy makers with a range of sometimes complementary lenses with which to assess current transitions and alternative future directions.

The various approaches or ways of thinking about transitions are presented in a summary table (ie Table 1 in page 6), which introduces the focus of each approach, its findings, and some of the main critiques levied against it. The table also explores possible implications that each approach may have for the transition, particularly in terms of the transition to renewable energy. Considering this issue from a variety of perspectives may help to identify dimensions of the problem that may eventually be neglected or less scrutinised. It may, in particular, shed light on the actors whose views should be factored in decision-making processes, on certain organisational and institutional linkages that may need strengthening, or on spatial scales of action that require greater attention.

What key messages can business and policy leaders distil from this review? The findings of the techno-economic approach usefully emphasize that radical and incremental innovation should be combined, as the latter tends to be key for the diffusion of new technologies to the greatest possible number of people. Recent findings of this approach note that, throughout history, the state has played a key role in facilitating incremental innovation that disseminates new technologies beyond elites. This highlights the fact that without well-functioning state institutions and government organisations, the capability to promote fundamental transformations towards, for example, renewable energy, will be severely diminished, and the transition is likely to fail. This risk is considered higher in developing and least developed countries, which represent an increasing share of the global economy.

As to the socio-ecological transitions approach, the work of authors in this line of thought demonstrates and reiterates that there is little hope for a new development cycle without renewable sources of energy. This conclusion derives from quantitative analyses of energy and material flows from nature into human society and back into the natural environment.

From the perspective of experts using a technological innovation systems approach, the key for a successful transition lies in the relationship across organisations involved in technological innovation. Strong and mutually reinforcing links among business organisations and between incumbent business actors and governmental entities are at the core of any transition. The establishment or emergence of such links is in great part derived from organisational and institutional innovation, on which technological innovation depends.

The literature using the multilevel perspective (MLP) starts by analysing historic trends of fundamental social and technological transformations. In doing so, this literature finds proof that transitions can occur through deliberate creation and support of strategic niches. A transition is effectively set in motion when simultaneous and mutually reinforcing learning processes make niches increasingly attractive. Eventually, learning gives origin to a stable set of social practices, and new technologies become socially embedded. The transition to a new state of affairs effectively materialises when powerful incumbent actors lend support to niches.

The second stream of research under the MLP research is dedicated to transition management and aims to provide knowledge that is readily accessible to national governments. It explicitly aims to study how targeted transitions can occur; what drivers and obstacles transition processes encounter today; and how they can be used or overcome most effectively. Under this line of work, the success of a transition depends on the development and maintenance of appropriate links between policy makers, scientists and stakeholders, primarily those operating at national level. Researchers advocate a practice-oriented approach to complex problems, emphasizing the importance of a ´learning by doing´ and ´doing by learning´ attitude. Ultimately, transitions can only be effective through a combination of pressure from the top (ie macro-level) in terms of physical and institutional structures, and pressure from the bottom (ie micro-level) in terms of social norms, values and practices.

A third stream of research under the MLP addresses issues of power, knowledge, agency, and politics. In this strand of literature, transition processes cannot be understood without detailed analyses of individual agency and processes of empowerment and legitimisation.

Findings suggest that efforts to transition to a low carbon economy must go beyond corporate and policy actors, and consider the views and priorities of consumers, civil society organisations and local communities. In the same vein, the knowledge used to guide transitions should go beyond formal expert knowledge to include locally embedded lay knowledge.

The social practices approach goes much deeper in the analysis of social norms and practices, identified as relevant in the first strand of MLP research (about historical socio-technical transitions). It argues that no transition occurs without fundamental transformation of social practices. The emphasis is put on the circulation and diffusion of ideas and new understandings of causal relationships, and ultimately on the emergence of new habits and socially sanctioned practices. In respect to energy transitions, this line of thought emphasizes the need to understand consumer behaviour, everyday routines, and shared social practices. It also advocates careful analysis of misaligned groups of actors, and their use of alternative technologies, institutions, visions and practices. These may constitute the seeds of innovation supporting the transition to a low carbon economy in new ways.

From a resilience approach, any decision on a transition path, or steps in a path, should be based upon a deeper understanding of the inter-dependences between social and ecological systems. These have a high level of complexity and therefore uncertainties should be acknowledged, accepted and explicitly assessed. There is a possibility that technological innovation may drive development in directions that are opposed to sustainability and reinforce inequalities in society.

Effective transitions to sustainability depend upon actors and organisations that acknowledge the limitations of their knowledge, are prepared to adapt to new circumstances, and are able to enact fundamental change. It focuses on the capabilities of actors to adapt and transform. These capabilities are considered to be stronger when those actors are well connected across space, and when these actor networks support social functions of experimentation, monitoring and learning. Ultimately, transitions rely on social and institutional innovation.

From a human geography perspective, the challenges and opportunities of transition are inextricably related to social, ecological and ultimately spatial contexts. Transitions require native forms of innovation, emerging from specific social, economic, institutional and ecological contexts, instead of ready-made solutions developed elsewhere. This also makes it important to consider inter-connections across spatial contexts. The local and the global often become inextricably connected, in a way that a local transition may often not succeed without the involvement of both types of actors. This also lends greater importance to global circulation of ideas and social norms, and to attempts to translate them to local contexts.

This strand of literature is also explicitly concerned with issues of inequality. These may emerge directly from asymmetries in economic and political power or indirectly from the uneven distribution of human impacts upon the natural environment. All in all, given that the outcomes of transitions are often geographically uneven and socially unequal, issues of social and environmental justice must be systematically analysed.

In the context of a 'just transition', the 'avenues of thought' and research gaps identified in this working paper highlight some key aspects that often remain outside the discussion. Any just transition agenda will need to include cultural and demand related aspects, and make inclusion an objective of innovation systems. In addition, the recognition of close interconnections between social, technological and ecological systems, calls for close monitoring and transparency regarding the intended and unintended consequences of technological innovation for the way in which social and ecological systems influence each other. Finally, the integration of a critical human geography lens seems instrumental for an integration of notions of justice across space. At all spatial scales, justice during the transition may be usefully considered from a deeply 'reflexive' approach to management and governance, which privileges processes of empowerment, accountability and legitimacy.

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Large tables

	The Techno-Economic Approach	Socio-Ecological Transitions Approach	Technological Innovation Systems	Based on the Multilevel Perspective (MLP)			Social Practices	Resilience approach	Human Geography approach
				Historical co-evolution of social and technological systems	Active management of on-going transition processes	Reflexive governance			
Focus	**Evolutionary economic theory** (after Kondratieff / Schumpeter) **Long-term economic development cycles** (40–60 years) Clusters of new technologies	**History of fundamental patterns of interaction between human society and natural systems** Social organisation of energy and material flows from and into the natural environment Decoupling human development from resource consumption	**Social and institutional conditions for the emergence of new technologies** Interplay between firms and other actors	**Social and technological systems co-evolve** through interaction between Micro level(niches), Meso level(regimes) and Macro level (landscape) **Historical emergence of transition dynamics** (not necessarily towards sustainability)	Recent and **on-going processes of transition**, with researchers active in the change process	Pervasive **role of agency and power** asymmetries Issues of **legitimacy** for government/firms/science	Everyday social practices Consumer behaviour Actor networks	**Social-ecological systems as a complex adaptive systems** characterised by uncertainty and non-linear feedback loops **Systematic learning** approach to the way societies interact and manage the natural environment	Politics of environmental decision-making across space and time (incl. environmental justice) Issues of social and ecological context
Findings	Explains how major **technological change induces macro-economic cyclical movements,** at national level Identifies five techno-economic eras in last 250 years Distinguishes different phases within an era Incremental innovation is important to diffuse technology deriving from disruptive innovation	Gives consideration to the natural environment in macro-economic development through material flow analysis. Transitions only occur when there is a structural change in a society's energy flows.	**Identifies key processes that need to run smoothly** for the innovation system to perform well **Pinpoints obstacles** to radical technological innovation for sustainability	Patterns of **change from below** (niches) Describes **strategic niche management**	**Multiple sources and patterns of change** and how they may be sequenced **Prescribes "transition management"** as practice-oriented model (doing by learning/learning by doing)	Different ways in which **power is present at the different levels** Insights on how strategic agency comes about	Innovation in social practices comes about through **networks of people, circulating ideas, and notions of appropriate behaviour**	Resilient social-ecological systems are characterised by **adaptability and transformability** at multiple scales of social organisation **Role of agents of change and their networks**, working simultaneously at different spatial scales	Beyond national innovation Interactions between **regimes operating across multiple spatial scales** (eg the influence of global forces in local decision processes) Important to strengthen capabilities of local government authorities
Implications for a transition to renewable energy	**Capability of the state** is key to extend access of new energy production technology beyond elites	**Technological innovation** should target the provision renewable sources of energy	**Government incentives to incumbent business** actors are important for the emergence and consolidations of technological innovation hubs	**Emergence** of technology as a result of consumer demand, and then embedded in social practices	Energy transition **steered towards a pre-defined goal by government actors and scientists** (eg Dutch energy transition)	More **inclusive and conscious decision processes, considering alternatives and sources of uncertainty**	Changes in what is valued results in **wholesome behavioural change** (new consumption practices)	Emphasises the **importance of social and institutional innovation** in the management and governance of renewable energy	transition unfolds differently according to **geographic context and spatial scale** **Incentives need to be taylor-made** and their impact closely monitored
Critique	**Inability to identify causes behind** long-wave cycles (eg over-deterministic view of macro-economic phenomena) Not able to analyse processes of change at smaller scales of social organisation	Given its macro-economic focus, **it does not consider the role of individual actors, belief systems, culture and political interests** (such as those associated with fossil fuel production and consumption)	**Marginalises cultural and social aspects of technology** Unable to understand why obstacles are there and therefore how to remove them **Excessive emphasis on large corporates and government actors**	Does not consider all pressures of change	**Little understanding of how problems are framed** and how policy and research priorities are politically and socially constructed	**Not reflexive enough** about processes through which **power imbalances** are replicated **Neglects demand side** actors such as consumers and social movements	May lose track of **political and economic incentives and mechanisms behind circulation of ideas** (eg government educational campaigns)	Weaker in the analysis of technological innovation issues Difficulties in operationalising adaptability and transformability in different contexts Does not fully explore the role of power asymmetries and how they may preclude adaptability and transformability	**May not fully grasp obstacles for change** within government and business organisations
				Insufficient understanding of **the role of power and politics** Concept of "levels" leads the observer into **hierarchical understanding of reality**; insufficient attention to the role of actor networks spanning multiple spatial scales **Spatial bias** towards national innovation					

Table 1. Ways of thinking about transition

The nature of transitions:
Implications for the transition to a low carbon economy