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Original research article

Disruption and low-carbon system transformation: Progress and new challenges in socio-technical transitions research and the Multi-Level Perspective

Frank W. Geels

Sustainable Consumption Institute & Manchester Institute of Innovation Research, The University of Manchester, Denmark Road Building, M13 9PL, Manchester, United Kingdom

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A B S T R A C T

This paper firstly assesses the usefulness of Christensen's disruptive innovation framework for low-carbon system change, identifying three conceptual limitations with regard to the unit of analysis (products rather than systems), limited multi-dimensionality, and a simplistic ('point source') conception of change. Secondly, it shows that the Multi-Level Perspective (MLP) offers a more comprehensive framework on all three dimensions. Thirdly, it reviews progress in socio-technical transition research and the MLP on these three dimensions and identifies new challenges, including 'whole system' reconfiguration, multi-dimensional struggles, bi-directional niche-regime interactions, and an alignment conception of change. To address these challenges, transition research should further deepen and broaden its engagement with the social sciences.

1. Introduction

Effective mitigation of climate change will require transitions towards low-carbon electricity, heat, agro-food, mobility and other systems. Since existing systems are locked-in and path dependent, these transitions will involve disruptions of the status quo and transformational changes in technology, user practices, markets, business models, policy, infrastructure and cultural meanings [1–3].

It is therefore timely that this Special Section in ERSS aims to assess the usefulness of Christensen's disruptive innovation framework [4] for energy system transformations. My contribution to this debate has three goals. Firstly, Section 2 acknowledges some useful insights of Christensen's framework, but also identifies several important shortcomings with regard to broader system transformation. These include two definitional limitations and three conceptual problems, which relate to units of analysis, limited multi-dimensionality, and a 'point source' view of change. Focusing on the three conceptual issues, the second goal is to demonstrate that the Multi-Level Perspective (MLP) usefully foregrounds relevant aspects of big phenomena like low-carbon transitions. Thirdly, again focusing on the three conceptual issues, the paper aims to take stock of progress in transitions research and the MLP in recent years, identify new challenges, and suggest directions for future research. The second and third goals are addressed together in Sections 3–5, which are organized along the three conceptual issues. Each of these sections first indicates why the MLP offers broader understandings than Christensen's framework, then offers empirical examples, and then discusses new challenges and conceptual elaborations. Section 6 concludes.

2. Strengths and weaknesses of the disruption innovation framework

Christensen [4] made important contributions to the long-standing debate in innovation management about new entrants, incumbents and industry structures. He argued that disruptive innovations enable new entrants to 'attack from below' and overthrow incumbent firms. Christensen thus has a particular understanding of disruption, focused mainly on the competitive effects of innovations on existing firms and industry structures. His framework was not developed to address systemic effects or broader transformations, so my comments below are not about the intrinsic merits of the framework, but about their usefulness for low-carbon transitions.

Christensen's disruptive innovation framework offers several useful insights for low-carbon transitions (although similar ideas can also be found elsewhere). First, it suggests that incumbent firms tend to focus their innovation efforts on sustaining technologies (which improve performance along established criteria), while new entrants tend to develop disruptive technologies (which offer different value propositions). Second, it proposes that disruptive technologies emerge in small peripheral niches, where early adopters are attracted by the

E-mail address: frank.geels@manchester.ac.uk.

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technology's new functionalities. Third, incumbent firms may initially overlook or under-estimate disruptive technologies (because of established beliefs) or are not interested in them, because the limited return-on-investments associated with small markets do not fit with existing business models. Fourth, price/performance improvements may enable disruptive technologies to enter larger markets, out-compete existing technologies and overthrow incumbent firms.

Nevertheless, Christensen's framework also has limitations that constrain its usefulness for low-carbon system transformation.[1] One definitional limitation is that Christensen's *disruptive* innovation concept would only draw attention to a sub-set of low-carbon innovations (namely those that introduce new functionalities or value propositions). It would thus exclude *sustaining* low-carbon technologies that meet existing performance standards with less carbon emissions (e.g. electric vehicles, wind turbines, light emitting diodes). Another definitional limitation is that Christensen has a somewhat idiosyncratic understanding of disruptive innovation as being cheaper than existing technologies, underpinning his view on 'attacks from below' (disruptive innovations first entering lower ends of the market and then migrating upwards). While this may apply to a sub-set of innovations, it unhelpfully excludes innovations that are initially more expensive and first enter the high or specialized end of the market. Utterback and Acee [5] give many historical examples. Solar-PV or Tesla's electric vehicles are contemporary low-carbon examples.

Christensen's framework also has several conceptual limitations for system transition. Firstly, it focuses on products or components (like hard disk drives or micro-processors) rather than comprehensive systems. It also focuses on *single* innovations, whereas system transformation is likely to entail interactions between multiple innovations. Secondly, it focuses on price/performance competition in markets, and ignores social, political, cultural and infrastructural dimensions. Consequently, it does not consider that changes in the selection environment (carbon taxes, subsidies, performance standards, regulations) may be important drivers of low-carbon transformation. Thirdly, the framework has a 'point source' approach to change, which understands disruption as being caused by (heroic) innovators conquering the world. While this approach is common in innovation management, it overlooks the possibility that major change and transitions may occur when new technologies *align* with broader ongoing processes such as political struggles, societal debates, and strategic games. For each conceptual limitation, the next three sections show how the MLP offers broader understandings, provide low-carbon transition examples, and identify new research challenges for transition research and the MLP.

3. Socio-technical systems and system reconfiguration

3.1. Broader MLP-understanding

Compared to Christensen's disruptive innovation approach, the Multi-Level Perspective (MLP) broadens the unit of analysis from technological products to socio-technical systems that provide societal functions such as mobility, heat, housing and sustenance. These systems consist of an interdependent and co-evolving mix of technologies, supply chains, infrastructures, markets, regulations, user practices and cultural meanings [6]. Sociotechnical systems develop over many decades, and the alignment of these different elements leads to path dependence and resistance to change. Existing systems are maintained, defended and incrementally improved by incumbent actors, whose actions are guided by 'socio-technical regimes', the semi-coherent set of rules and institutions [7].

The MLP argues that sociotechnical transitions come about through interacting processes within and between the incumbent regime, radical niche-innovations and the sociotechnical landscape [8–10]. Niche-innovations are emerging social or technical innovations that differ radically from the prevailing sociotechnical system and regime, but are able to gain a foothold in particular applications, geographical areas, or with the help of targeted policy support [11]. The sociotechnical landscape refers to broader contextual developments that influence the sociotechnical regime and over which regime actors have little or no influence. Landscape developments comprise both slow-changing trends (e.g. demographics, ideology, spatial structures, geopolitics) and exogenous shocks (e.g. wars, economic crises, major accidents, political upheavals).

The MLP suggests that transitions come about through the alignment of processes within and between the three levels (Fig. 1). In a nutshell, radical innovations emerge in peripheral niches in phase 1, and stabilize and enter small market niches in phase 2. Breakthrough in phase 3 depends on niche-*internal* drivers such as price/performance improvements, scale and learning economies, the development of complementary technologies and infrastructures, positive cultural discourses, and support from powerful actors. But diffusion also depends on *external* windows of opportunity, due to regime destabilisation because of landscape pressures or persistent internal problems. Regime transformation occurs in phase 4, including adjustments in infrastructures, policies, lifestyles and views on normality.

While the MLP positions many of Christensen's insights in a broader framework, many applications implicitly maintain the focus on *singular* innovations (which is also visible in the single bottom-up graph in Fig. 1). The focus on single innovations (like solar-PV, wind turbines, biogas, electric vehicles) also permeates the Strategic Niche Management and Technological Innovation System literatures. While niche-innovations are important, this singular focus falls short of foundational interests in *system* innovation [1,2].

3.2. Empirical examples of low-carbon system reconfiguration

The current unfolding of low-carbon transitions suggests, however, that system change may also occur through interactions between *multiple* innovations. Low-carbon transitions in electricity, for instance, depend not only on radical innovations like renewables (wind, solar-PV, bio-energy, geo-thermal), but also on hybridization between niche-innovations and regimes (coal-with-CCS, coal-with-biomass) and on complementary innovations in electricity networks and demand, e.g. network expansion (to increase capacity, connect remote renewables and link to neighbouring systems); smarter grids (to enhance flexibility and grid management); energy storage (e.g. batteries, flywheels, compressed air, pumped hydro); demand response (e.g. new tariffs, smart meters and intelligent loads); and new business models and market arrangements (such as capacity markets to ensure system security). Together these innovations may transform the entire electricity system.

Similarly, low-carbon system transitions in mobility could go beyond green cars (biofuels, hybrids, plug-in hybrid, full-electric, fuel cell) and also address broader changes in the personal mobility system such as new business models (car sharing, car-pooling, Uber), changing user practices (e.g. modal shift towards trains, trams, buses, cycling or tele-conferencing or tele-work, which reduces the need to travel), integration of Information and Communication Technologies in self-driving cars, dynamic traffic management, intelligent transport systems. More broadly, mobility can be reconfigured through linkages between systems. Urban planning and transport systems, for instance, can be integrated via transit-oriented development (building mixed-use areas around public transport stops), compact cities, and intermodal transport, which facilitates mode-switching with seamless transfer facilities, smart cards, and aligned time-tables [13].

[1] In this paper, I use the terms 'transformation' and 'transition' interchangeably to refer to substantial change (depth) in energy, mobility, agro-food systems across multiple dimensions (scope).