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Review

Reducing energy demand through low carbon innovation: A sociotechnical transitions perspective and thirteen research debates

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ABSTRACT

Improvements in energy efficiency and reductions in energy demand are expected to contribute more than half of the reduction in global carbon emissions over the next few decades. These unprecedented reductions require transformations in the systems that provide energy services. However, the dominant analytical perspectives, grounded in neoclassical economics and social psychology, focus upon marginal changes and provide only limited guidance on how such transformations may occur and how they can be shaped. We argue that a socio-technical transitions perspective is more suited to address the complexity of the challenges involved. This perspective understands energy services as being provided through large-scale, capital intensive and long-lived infrastructures that co-evolve with technologies, institutions, skills, knowledge and behaviours to create broader 'sociotechnical systems'. To provide guidance for research in this area, this paper identifies and describes thirteen *debates* in socio-technical transitions research, organized under the headings of emergence, diffusion and impact, as well as more synthetic cross-cutting issues.

1. Introduction

Improvements in energy efficiency and reductions in energy demand are widely expected to contribute more than half of the reduction in global carbon emissions over the next few decades [1]. To provide a reasonable (66%) chance of limiting global temperature increases to below 2 °C, global energy-related carbon emissions must peak by 2020 and fall by more than 70% in the next 35 years. As an illustration, this implies a tripling of the annual rate of energy efficiency improvement, retrofitting the entire building stock, generating 95% of electricity from low-carbon sources by 2050 and shifting almost entirely towards electric cars [2]. The rate and scale of change required is best described as revolutionary: there are few historical precedents and existing policy initiatives have achieved only incremental progress towards those ends [3].

Major reductions in energy demand will require the widespread uptake of technical and social innovations. The paper focuses on ***demand-side low-carbon innovations***, which refer to new technologies, organisational arrangements and modes of behaviour (or social practices) that are expected to improve energy efficiency and/or reduce energy demand. This broad definition encompasses both incremental and radical innovations relevant to all energy using sectors. Fig. 1[1] provides some relevant examples, broadly classified by their degree of technical or social novelty.

To date, most policy efforts have focused upon technically and socially incremental options (in the bottom left quadrant of Fig. 1). While these are important in the short term, they face diminishing returns in the long term, since their potential for further diffusion is limited. Hence, more substantial demand reductions are likely to require more radical innovations that are presently at an earlier stage of emergence and require larger changes to existing sociotechnical systems.

The two dominant approaches that have, so far, underpinned most policy efforts (neo-classical economics and social psychology) have strengths, but also important limitations for understanding both the emergence and diffusion of radical innovations and the associated system transformations [4]. Neoclassical economics considers energy or carbon prices to be the critical variable in reducing energy demand, supported where appropriate by policies to reduce economic barriers to energy efficiency, such as split incentives, asymmetric information, high transaction costs and difficulties in accessing finance [5–8].

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[1] Radical innovation need not only refer to 'new to the world' innovations, like 3D-printing. Radical innovation can also refer to 'new to the city' (e.g. district heating, light-rail) or 'new to the organization' (e.g. tele-conferencing).

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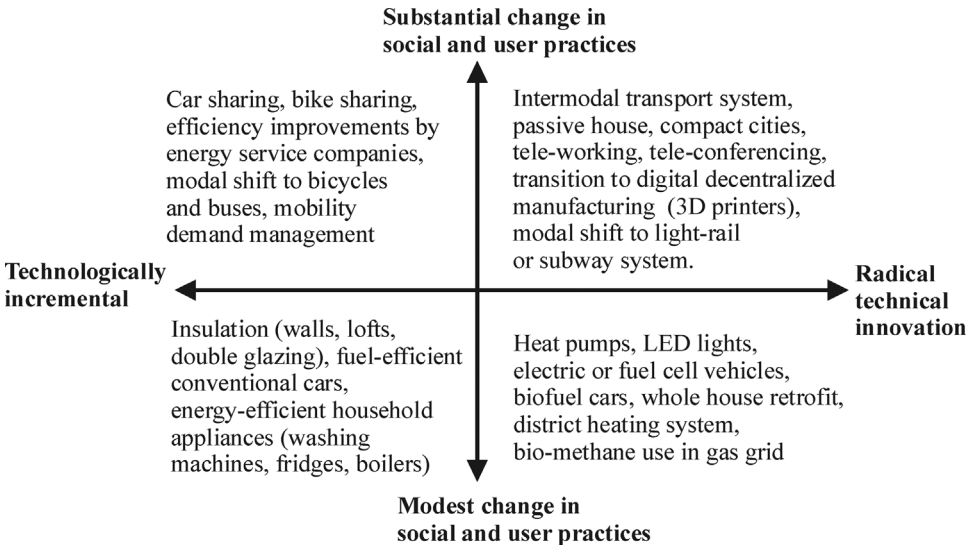

Fig. 1. Variety of low carbon innovations with different degrees of social and technical novelty.

Neoclassical economics also provides a rationale for supporting new, energy efficient technologies at different stages of the 'innovation chain', but offers only limited insights into either the process of innovation or the most effective means of policy support.

These recommendations have at least three drawbacks. First, for most consumers energy efficiency represents a secondary and largely invisible attribute of goods and services, thereby muting the response to economic incentives. Factors such as comfort, practicality and convenience commonly play a larger role in energy-related decisions, with energy consumption being dominated by habitual behaviour shaped by social norms [9,10]. Second, carbon pricing is politically unpopular and energy efficiency remains a low political priority, resulting in a policy mix that is frequently weak and ineffective [11]. Third, neoclassical economics assumes rational decision-making by firms and individuals and tends to pay limited attention to the broader, non-economic determinants of decision-making [12].

Insights from behavioural economics and social psychology provide deeper insights into the cognitive, emotional and affective influences on relevant choices and routines and suggest ways to 'nudge' people and organisations towards more energy efficient choices and routines [13–15]. But social-psychological research focuses overwhelmingly upon individual consumers and under-appreciates the importance of interactions with other actors, organisational decision-making and economic and social contexts. More fundamentally, both economic and social psychology have an individualist orientation that underrates the significance of the collective and structural factors that shape behaviour, guide innovation and enable and constrain individual choice.

Thus, the dominant perspectives on reducing energy demand have a number of limitations and these limitations are reflected in the partial focus and relative ineffectiveness of the current policy mix. Given this, we propose a broader socio-technical perspective that more fully addresses the complexity of the challenges involved as well as integrates relevant insights from various social science disciplines.

A socio-technical transitions perspective is more appropriate for two reasons. First, energy services such as heating and mobility are provided through large-scale, capital intensive and long-lived infrastructures that *co-evolve* with associated technologies, institutions, skills, knowledge and behaviours to create broader 'sociotechnical systems' [16–22]. These systems are termed 'sociotechnical' since they involve multiple, interlinked social and technical elements, such as technologies, markets, industries, policies, infrastructures, user practices and societal discourses. Second, a transitions perspective acknowledges specificities of the kinds of change processes involved. Sociotechnical systems have considerable inertia, making it difficult for radically different (and more sustainable) technologies and behaviours to become established – such as electric mobility or mass transit schemes. Hence, reducing energy demand involves more than improving individual technologies or changing individual behaviours, but instead requires interlinked and potentially far-reaching changes in the systems themselves – or 'sociotechnical transitions'. These transitions are typically complex, protracted and path dependent and the outcomes are difficult to predict. A socio-technical transitions perspective acknowledges these characteristics, while neo-classical economics and social psychology do not.

The socio-technical transitions perspective has received much attention in recent years [3,22–25]. In fact, authors have made so many and diverse contributions in recent years that there is a risk of not seeing the forest for the trees. Our key contribution is therefore to inductively identify and describe thirteen key debates within this literature that are relevant for energy demand reduction. Our aim is to construct a research map useful for guiding future research.

We have organized our discussion along three research themes: emergence, diffusion and impact. Although this is suggestive of a linear model of innovation, we think the distinction is useful since each theme encompasses very different analytical topics. *Emergence* and *diffusion* of radical demand-side low carbon innovations refer to different phases in decades-long transition processes (although the boundaries between them may be fuzzy). *Impact* refers to the ultimate effect of low carbon innovations on energy demand. Acknowledging complexities, we also identify crosscutting debates that span the three themes. The focus throughout is on theoretical and conceptual issues rather than specific empirical topics. Many of the debates are relevant to research on 'sociotechnical transitions' in general as well as to research on energy demand in particular.

The paper proceeds as follows. Section 2 briefly introduces the sociotechnical transitions perspective on low carbon innovation and contrasts this with more mainstream approaches to understanding innovation. Section 3 then explores the *emergence* of low carbon innovations from a sociotechnical perspective and identifies five debates on which further research is required. Section 4 briefly conceptualizes the *diffusion* of low carbon innovations and identifies three pressing debates. Section 5 addresses the *impact* of low-carbon innovations on energy demand and identifies three further debates. Section 6 then highlights two cross-cutting debates that span all three themes, while Section 7 concludes.