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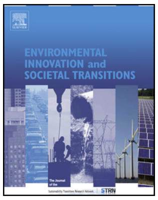

Modelling energy transitions for climate targets under landscape and actor inertia

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ABSTRACT

The speed at which established socioeconomic and technological systems can be adapted to alternatives that are compatible with a climate stabilised, 2 °C world remains unknown. Quantitative models used for assessing this challenge typically make a number of arguably optimistic assumptions regarding human behaviour and decision making. This often restricts the insights produced to futures approximating a so-called *first-best* policy landscape. However, empirical studies of socio-technical change have shown that technological diffusion is often influenced by actors and institutions interacting under less ideal, *second-best* conditions. This paper quantifies these factors in a formal energy model as *landscape and actor inertia* and employs them for the first time in BLUE, a dynamic stochastic socio-technical simulation of technology diffusion, energy and emissions inspired by the multi-level perspective. Using the UK energy system as an example, the results illustrate how socio-technical inertia may significantly blunt future efforts to achieve climate targets.

1. Introduction

1.1. Modelling energy transitions in "second-best" policy worlds

The Paris Agreement sets out an international framework for stabilising emissions of greenhouse gases (GHGs), with an aspirational target to hold mean global temperature rise to at least 2 °C by the end of the century (UNFCCC, 2015a). The Intergovernmental Panel on Climate Change (IPCC) has shown that to have a "likely" (>66%) chance of achieving this goal, global emissions must fall rapidly by mid-century and be almost negligible by 2100 (IPCC, 2014). While current national pledges fall short of action consistent with this target (UNFCCC, 2015b), and the framing of the targets as temperature limits is itself, contested (Victor and Kennel, 2014), it is agreed that an effective mitigation response will require large-scale changes to established energy systems (Bruckner et al., 2014).

The scale of the energy transition challenge is extremely daunting. While there is a diversity of views on which technological, behavioural, lifestyle and political changes might be required in different contexts and at different scales, a common theme runs through almost all of the literature: the urgency required for the transition. While the theoretical possibility of achieving climate targets is generally accepted, the speed at which established socioeconomic and technological systems can be adapted to alternatives that are compatible with a 2 °C world remains unknown.

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Quantitative models used for assessing this unprecedented challenge typically make a large number of arguably optimistic assumptions regarding human behaviour and decision making, as well as future social and political conditions. A majority of long-term decarbonisation studies assume that key actors will make investment decisions in a rational, cost optimal fashion, and that future governments will be able to forge a social consensus that is conducive to taking action in spite of resistance from vested interests. Most studies also assume that a political mandate can be obtained to put in place long-term policies to price externalities and correct the market failures that lead to GHG pollution. Work using these idealised assumptions, sometimes referred to as "first-best" conditions, is often critiqued as overestimating the speed of transitions while simultaneously underestimating their costs (Bertram et al., 2015). There is therefore a strong interest in exploring climate targets under so-called "second-best" worlds where the "messy policy landscape" found in reality is better acknowledged (Strachan and Usher, 2011).

It is argued that capturing the behaviour of key energy system actors, and in particular, how their behaviour might co-evolve through time as energy transitions unfold, is key to improving the utility of energy economic models for policy design (Hughes and Strachan, 2010). A classic taxonomy of energy economic models, developed by Hourcade et al. (2006), identifies macro-economics, technological detail, and micro-economic realism as the key dimensions of study required for future advancement of the field. We argue in this paper that improving the representation of decision making and actor dynamics in energy models requires not only a better depiction of investment choices in the micro-economic sense, but also a broader set of structural changes aimed at improving overall societal realism. To inform this perspective we draw on the substantial insights provided by the interdisciplinary field of socio-technical transitions (Chappin and Ligtvoet, 2014).

1.2. The multi-level perspective (MLP) on socio-technical transitions

The behaviour of key institutions or actors has been observed as a major factor influencing past technological transitions, suggesting that technologies are firmly embedded within particular social and political contexts (Geels, 2005). The literature on socio-technical transitions advocates the concept of studying not only technologies, but their role in society as part of integrated "socio-technical systems". This expands the common, engineering-derived definition of "system" to include not only networks of technological artefacts but also the associated supporting institutions and individuals who use them (Hughes, 1987; Ottens et al., 2006). Benjamin Sovacool sums up the co-evolving nature of socio-technical change by observing that *"To be successful, technologies must not only get built, but get built into society"* (Sovacool, 2009).

As noted above, a rapid energy transition towards a 2 °C world by the mid-21st century implies a radical restructuring of the established order, which is dominated by fossil fuel technologies, infrastructures and institutions. Together, these form what is often referred to in the literature as a powerful "socio-technical regime", effectively a reigning champion that is difficult for new challengers to displace. A strong incumbent regime not only dominates the playing field but also to some extent affects the rules of the game by which others must play. It's very existence creates path dependencies and socio-technical "lock-in" to an environmentally harmful paradigm (Arthur, 1989; Unruh, 2000). Studying the conditions which enable systems to break out from locked-in states is a key activity in the transitions research community (Markard et al., 2012).

One of the most widely used frameworks for exploring socio-technical change is the multi-level perspective (MLP) of Geels (2011) (see Fig. 1). Essentially, under the MLP framework, innovative "niche" technologies have their performance and costs improved over time under the support of powerful actors (Fouquet, 2010). Shifts in macro-scale "landscape" conditions, such as government intervention in markets or changes in social preferences (Unruh, 2002; Dolfsma and Leydesdorff, 2009) may then create periodic windows of opportunity for these innovations to disrupt the status quo and enter the mainstream. In this paper, we aim to replicate these dynamics in a quantitative model for the purposes of analysing the viability of achieving climate targets in a national energy system. We note that quantitative model outputs still require qualitative interpretation, and we see this formal modelling activity as one that must be developed in parallel with qualitative studies of transitions (we elaborate further in discussion under Section 5.2).

1.3. Actor and landscape inertia

The historical diffusion of innovative energy technologies into mainstream use has generally been slow, occurring along decadal timescales rather than in the space of a few years. An extensive review by IIASA researchers found that energy technologies have historically taken between 80–130 years to achieve market dominance from their initial commercialization (Wilson and Grübler, 2011). To limit anthropogenic warming along the timescales required by the Paris Agreement, transitions to new energy technologies may need to occur at rates that could be considered extremely rapid by historical standards.

Researchers have speculated about the social and political conditions that could be required to bring about such a rapid shift. Some have invoked the idea of conditions approximating a "war economy" or the Apollo space program to bring about a completely transformed energy system in 40–50 years (García-Olivares and Solé, 2015; Delucchi and Jacobson, 2011), while sceptics have noted that these herculean efforts have historically been difficult to sustain over long periods, typically burning out after less than a decade (Kramer and Haigh, 2009). Running a war economy requires political and social consensus, which is currently absent from the energy transition landscape. Currently, we observe that the dominance of the incumbent fossil-fuelled regime is facilitated by macro-scale social and political conditions (referred to in the MLP tradition