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Learning pathways for energy supply technologies: Bridging between innovation studies and learning rates

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ABSTRACT

Understanding and supporting learning for different emerging low carbon energy supply technology fields is a key issue for policymakers, investors and researchers. A range of contrasting analytical approaches are available: energy system modelling using learning rates provides abstracted, quantitative and output oriented accounts, while innovation studies research offers contextualised, qualitative and process oriented accounts. Drawing on research literature and expert consultation on learning for several different emerging energy supply technologies, this paper introduces a 'learning pathways' matrix to help bridge between the rich contextualisation of innovation studies and the systematic comparability of learning rates. The learning pathways matrix characterises technology fields by their relative orientation to radical or incremental innovation, and to concentrated or distributed organisation. A number of archetypal learning pathways are outlined to help learning rates analyses draw on innovation studies research, so as to better acknowledge the different niche origins and learning dynamics of emerging energy supply technologies. Finally, a future research agenda is outlined, based on socio-technical learning scenarios for accelerated energy innovation.

1. Introduction

National and international policy ambitions for greenhouse gas emissions reduction and low carbon technology deployment have focused attention on energy system transformation [1,2]. One of the key dynamics – and uncertainties – associated with this envisaged transformation relates to the development and deployment of low carbon energy supply technologies. While technological innovation holds out considerable promise as an enabler of more affordable energy system change [3,4], this promise is highly uncertain, particularly over decades-long timescales.

Technological innovation in the energy sector is driven by a complex mix of incentives and interests [5,6], and there is now a large number of emerging low carbon energy supply technology fields, each supported by particular policy initiatives, investment programmes, developer firms and research institutions. Making sense of this activity – in terms of systematic ordering, comparing and assessing its effectiveness and potential – has become a major policy and research challenge in its own right [3,7,8].

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A range of tools and frameworks are drawn on, including technology roadmaps [1,9], energy system models [3,10] and explorative scenario planning techniques [11,12]. Each provides particular insights. Technology roadmaps specify the envisaged sequences involved in the progressive commercialisation of emerging technologies in considerable detail. System modelling provides 'structured insights' into the interactions and trade-offs between different parts of the whole energy system, for example, between supply and demand, or between different supply options [13,14]. Explorative scenario exercises allow for explicitly considering alternative possible futures in the context of social and economic trends and potentially disruptive events [15]; they may therefore capture more diverse combinations of envisaged social and technical futures, and the non-linearities of change, than either system models or roadmaps.

These different techniques are not mutually exclusive, and indeed, they are sometimes used in combination [16]. At the same time, each approach has its limitations. Roadmaps may under represent the wider socio-technical context for innovation — those factors beyond the control of the technology system in question, including interactions between different technologies and the more socio-political aspects of innovation, which are often especially important for energy technologies. Different roadmaps may also articulate inconsistent levels of optimism or ambition across different technology communities. This is especially problematic in early stage technology assessment because of a lack of any empirical track record, and a tendency to 'appraisal optimism' [17] or even hype [18].

Energy system models, in elaborating a broad system level view, may over simplify, either by under-representing the uncertainties, contingencies and non-linearities of system change, or by only allowing for highly aggregated representations of key system drivers such as technological innovation. Even relatively detailed bottom-up energy system models tend to characterise supply technologies by a small set of parameters, such as capital and operating cost, resource availability and conversion efficiency, with innovation dynamics often represented by a single parameter — the experience (or learning) rate [19] (the term 'learning rate' is used in this paper because of its resonance with the concern here for learning effects). Reducing down innovation processes to a single aggregate parameter means that many of their important properties go unrepresented, such as the qualitative difference between the early stage and later stage innovation dynamics, or the often key role of market diversity, including niche markets, in the early stage innovation [30,67]. Finally, explorative scenarios (and also system modelling) may provide only rather 'broad-brush' characterisations of socio-technical trends or possible step changes, and lack any detailed account of the causal mechanisms (agents, institutions or policies) by which their envisaged outcomes may be realised [20].

Alongside these widely used tools and methods is a body of social science research – technology and innovation studies (referred to hereafter as 'innovation studies') – which also analyses the dynamics of emerging technology systems. Low carbon innovation studies has become a highly active research field over recent years, developing and applying frameworks such as Technological Innovation Systems (TIS) [21–23] and the Multi-Level Perspective (MLP) on system transition [24–27]. Although the TIS and MLP have distinctive strengths and weaknesses [28] both provide highly detailed, contextualised and contingent accounts of innovation, in terms of interwoven and co-evolving social and technical elements. Case study research based on these frameworks has provided many richly detailed case histories of the evolution of energy technology systems [29–31].

However, despite a shared concern for understanding the role of technological innovation in system change, there is strikingly little cross-over between the abstracted representations of technology learning in learning rates and system modelling, and the contextualised, contingent accounts of innovation studies. The premise for the learning pathways framing outlined below is that there are missed opportunities for cross-disciplinary interaction here, and in particular, that innovation studies accounts offer a valuable resource to enrich learning rates analyses. For example, system modelling using learning rates sees techno-economic performance, measured as a unit cost, as the principal factor in technological change, while innovation studies see references as a broader set of forces (including knowledge flows in early stage innovation, social and political legitimacy and the enabling or blocking role of incumbent organisations) [21–23].

The aim of this paper is to develop an analytical framework that allows systematic comparison of emerging energy technologies, whilst retaining some of the contextualised and contingent specificity of innovation studies. The formidable task of developing a full synthesis bridging the underlying assumptions of system modelling and innovation studies is beyond the scope of this paper. Instead, we take a socio-technical innovation studies approach as a starting point, and aim to improve comparability without losing too much specificity. Our efforts are inspired by earlier attempts within innovation and organisational studies at developing frameworks for technology comparison [32–38].

Within this 'comparability-oriented' stream of innovation studies, the learning pathways approach pays particular attention to the differing socio-technical niche origins of emerging energy technologies, and relatedly, the different learning styles involved in their development. By describing a small number of archetypical learning pathways, the prospect is opened up of more contextualised technology specific learning narratives that nevertheless are standardised enough to allow comparison, and inform learning rates analyses. In this way, the learning pathways matrix offers new insights on energy technology niche origins and learning pathways, and helps bridge between system modelling and innovation studies.

The paper proceeds as follows. Section 2 summarises and compares representations of technology learning in system modelling exercises using learning rates and innovation studies, and suggests the value of a new analytical framework; Section 3 describes the development of the learning pathways matrix, drawing on detailed analyses of the niche origins and learning effects for a set of emerging energy supply technologies; Section 4 applies the learning pathways matrix to describe the learning path histories of selected energy supply technologies, and the contemporary context for learning. Section 5 addresses prospective learning pathways, by setting out a set of archetypal learning pathways in the context of accelerated energy system change, and also, outlines a future research agenda for sociotechnical learning scenarios. Section 6 summarises and concludes the paper, and identifies some additional avenues for future research.

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