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Technology scale and supply chains in a secure, affordable and low carbon energy transition ☆

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HIGHLIGHTS

- Energy systems need to decarbonise, provide security and remain affordable.
- There is uncertainty over which technologies will best enable this to happen.
- A strategy to deal with uncertainty is to assess a technologies ability to show resilience, flexibility and adaptability.
- Scale is important and smaller scale technologies are like to display the above characteristics.
- Smaller scale technologies are therefore more likely to enable a sustainable, secure, and affordable energy transition.

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ABSTRACT

This research explores the relationship between technology scale, energy security and decarbonisation within the UK energy system. There is considerable uncertainty about how best to deliver on these goals for energy policy, but a focus on supply chains and their resilience can provide useful insights into the problems uncertainty causes. Technology scale is central to this, and through an analysis of the supply chains of nuclear power and solar photovoltaics, it is suggested that smaller scale technologies are more likely to support and enable a secure, low carbon energy transition. This is because their supply chains are less complex, show more flexibility and adaptability, and can quickly respond to changes within an energy system, and as such they are more resilient than large scale technologies. These characteristics are likely to become increasingly important in a rapidly changing energy system, and prioritising those technologies that demonstrate resilience, flexibility and adaptability will better enable a transition that is rapid, sustainable, secure and affordable.

1. Introduction

In common with other countries, the UK faces a challenge to decarbonise its energy system whilst maintaining energy security and affordability. This paper examines the underexplored relationships and importance of technology scale within the context of supply chains, in enabling these goals for energy policy to be met.

The supply chains that make up the component parts of energy systems have evolved over many decades to meet society's needs for power, heat, transport, manufacturing and services. They are complex and dynamic, involving many different actors, technologies, fuels, operating at different scales and locations, and are shaped by the policies, rules and regulations that are in place. Most energy systems are dominated by fossil fuel supply chains, which for the most part, are mature and globalised, but they are prone to inertia; and are increasingly struggling to collectively deliver on the three main goals of energy policy (Section 2).

To move towards a more sustainable and secure energy system requires a significant transition within current energy systems. A number of scenarios have been developed to consider different transition pathways and these suggest a growing role for electricity within the energy system, which could be provided by a range of low carbon technologies, such as nuclear power and renewable energy. However, they also indicate that no single technology will be able to decarbonise the energy system, and as such options need to be kept open.

During a transition, energy security also needs to be maintained, and this requires energy systems that can deal with short term shocks and longer term stresses to ensure continuity between supply and demand. Resilience is a helpful way to consider this, as it describes the ability of a system or supply chain to return to its original state after a disruption. With the exception

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of unconventional oil and gas, fossil fuel supply chains have evolved to be quite resilient. However, it is less clear how effective alternative supply chains, such as nuclear power or renewable energy technologies, will be in providing security (Section 3).

Given the uncertainties that exist, and the range of technology options that could play a role, a key issue will be to identify those technologies that show characteristics of resilience, whilst also showing flexibility and adaptability. There are a number of factors that could help to determine this, such as the speed at which a technology can be deployed, how compatible it is with the system and other technologies, and any constraints it may face socially, environmentally or economically (Section 4). A focus on technology scale and supply chains could provide an important mechanism by which these sorts of issues can be considered. To examine this, two low carbon technologies are explored, large scale nuclear power and small scale solar photovoltaics (Section 5).

The paper is organised as follows: Section 2 provides context on supply chains, considers how they relate to energy systems, and examines how they emerge and become established; Section 3 examines the complexity of energy security and how it relates to the wider UK energy policy goal for decarbonisation; Section 4 considers these issues in relation to a low carbon energy transition, supply chains and technology scale; Section 5 provides a detailed examination of nuclear power and solar PV, considering their role within energy systems, their supply chains, possible costs, and what this may mean for the UK; and Section 6 summarises the findings and provides conclusions.

2. Conceptualising energy supply chains

Supply chains, or value chains, are complex, dynamic and often globalised interconnected networks which comprise the entire sequence of activities involved in the delivery of a service or a product, from production through to end use and disposal [1–3]. They include multiple actors, operating at different scales and locations and cover the process by which components and products are produced, combined and delivered [4–6].

At a macro level any energy system can be considered as a supply chain (Fig. 1 – [6]) that contains multiple and interrelated subchains relating to suppliers and customers, based on different fuels, technologies, and the infrastructure that connects them; as well as the materials, labour and equipment needed for the development, manufacture, installation and operation of the system [6]. These supply chains are shaped by the policies, institutions, regulatory frameworks and practices that are in place within a country, as well as the wider interconnections it has to other energy systems, and the markets, rules, and regulations that shape them [7,8]. The primary purpose of the system is to meet the energy service demands of end users for power, heat and transport, across the economy [6].

Historical energy transitions have played an important role in shaping the supply chains that are in place. Within the UK, the system has evolved from using wood as the primary source of energy, into coal, and more recently oil, gas and electricity [9]. With these transitions in fuel type there have also been multiple coevolving innovations: socially; politically; institutionally; and technically [10,11]. An important recent innovation has been the liberalisation of the energy system in the UK (and a number of other countries) [12], resulting in a national energy system that is increasingly shaped at the international level, in terms of capital, technologies, fuels, and the ownership of equipment and energy companies [13].

Collectively these historical developments have resulted in a series of supply chains which are now mature, highly interconnected and complex [6]; and these have evolved over several decades, leading to a system that now relies on embedded technical and social commitments, making them prone to inertia and lock-in [14,15].

The mechanism by which different technology supply chains emerge and become established is, in part, a reflection of the innovation process [16]. For newer technologies, compared to incumbents, there are a range of internal and external risks, reflecting the immaturity of a technology and its supply chain, which will need to be overcome in order for technologies to be delivered [17]. As a technology comes to market, the supply chain associated with it broadens to bring in skills and resources associated with its deployment, such as: planning; design; manufacturing; construction and installation; operation and maintenance; and decommissioning; as well as associated sectors like legal and financial services [18].

For any technology there are a range of factors that influence its development. There can be bottlenecks or constraints along an entire supply chain, from the source of raw materials through to decommissioning that can, without mitigation, impact on the scale of development, deployment or operation [19]. These are important because technologies can only develop as fast as the tightest supply chain bottleneck allows [20]. There can also be more pervasive cross-cutting issues (Table 1) that impact across different technology supply chains (which can also be experienced as technology specific bottlenecks) [6]. To some degree these issues will vary between countries depending on the technologies and policies in place, although globalisation can also mean they are experienced across different regions simultaneously [21].

For a number of reasons the supply chains that make up energy systems are now under pressure, particularly in terms of their ability to deal with key challenges of ensuring energy security and the decarbonisation of supplies [12,29], which this paper goes onto consider.

3. Energy security in a carbon constrained world

Although no energy system can be completely secure [30], a central and high priority policy goal for all nations is energy security [31]. There is not a precise definition for energy security [32],

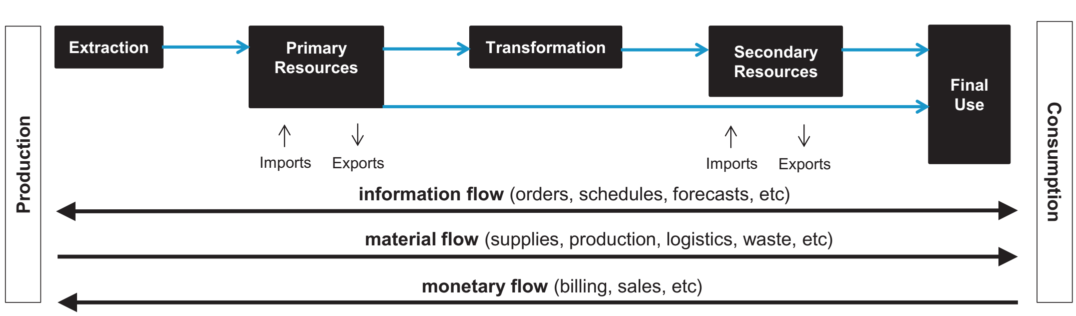

Fig. 1. The energy system as a supply chain. *Source:* [6].

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