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Introduction

a) In the context of answering the questions posed, we suggest that understanding the relevant risks arising in the supply chain is of central importance. A 'barrier' is better thought of as a risk to achieving the desirable outcome. All activities, actions, and programmes give rise to, or attract, risk. This is irrespective of whether they occur in the public or private domain, and independent of industrial or commercial sector. Risks arising in the supply chain of energy or fuels are frequently under-appreciated – we note that risk is barely addressed in the British Energy Security Strategy [1].

b) A rank ordered list of risks (according to total impact) relevant to the UK energy system is given in the Appendix [2]. Furthermore, investment – and policy instruments to remove barriers to investment – should be understood in the context of the gross fixed-capital formation (GFCF, a national accounting term) as a measure of total economic investment.

c) Risks occur everywhere along supply chains (UK and non-UK), and many UK supply chains have some dependence on non-UK entities or activities. Single risks (types of risk) are not evenly spread along the supply chain, and do not necessarily have the same importance for different fuels or energy vectors.

d) Such risks have many characteristics and components which can be conveniently grouped into categories: economic, environment, innovation, manufacturing, political, skills, and technical. In our work, we define environmental risk as being presented <u>by</u> the environment (e.g. severe weather events). Some technical risks present risk <u>to</u> the environment (or human health).

e) We define energy security as the low-risk (dependable) meeting of needs for energy within the economy [3]. The transition to low-carbon sources of energy is changing risk in the energy system in many different ways [4]. The ability to determine how risk varies with configuration of the energy system is crucial in guiding us to energy choices and policies aimed at improving energy security.

f) The risk profiles of future national energy systems [5] can be assessed to 2035 and beyond using well-known scenario sets such as those produced by National Grid [6] or the Climate Change Committee [7].

Summary

To be able to remove barriers to desirable outcomes it is necessary to understand the risks in current and new markets. The need to identify, locate, and analyse the detail of risks that arise in supply chains for energy systems is urgent. Private companies make investment decisions incorporating a risk assessment; governments should do likewise. At present, it appears that decisions are based on the output from energy systems models which omit explicit consideration of risk (other than through a pricing mechanism). Although risk has been recognised, it is often poorly defined or used in a restricted or informal sense. Risk is rarely treated rigorously, nor are systemic risks considered fully. The frequently changing policy and regulatory landscape in the UK suggests that the country has not yet achieved a stable platform for energy (security) policy development. The key to improving UK supply chains for energy security lies in assessing the different types of risk in the energy system and promoting appropriate policy to address their causes. We recommend a rethink of policy towards Demand Reduction, which should be making important contributions both to meeting the net-zero goal, and to the UK economy.

1 How can UK plc capture its fair share of the economic potential of emerging or less developed energy technologies?

1.1 Lack of vocational skills in the UK is widely recognised as a barrier (a risk) to its energy industry and its ability to make and deploy the new technology. To expand the ability of the UK to 'capture its fair share' of the potential of new technologies, many more young people need to be attracted into skills-oriented vocational training between the ages of 16-21 (not just ages 16-18), rather than trying to pursue an academic course at university. We recognise that there is likely to be 'special pleading' by some in the energy industry, so companies need to be encouraged or incentivised to train directly the staff they need, particularly in the light of the number of UK citizens claiming out-of-work benefits. The lack of support for meaningful work-based apprenticeships (not degree apprenticeships) is an area of concern.

1.2 The claims made by specific technology champions need to be examined more closely; optimism bias as a risk is difficult to define, but is observable. The failure of tidal stream and wave technologies to deliver the claimed potentials are one example. Similarly, severe optimism bias is evident in the infant bioenergy industry, leading to unrealistic expectations from complex technologies and dubious claims about the quantity of resources available.

1.3 Testing more rigorously the claims made by specific technology champions would enable better targeting of resources, engineering expertise and technical skills towards deployment. There is an opportunity cost in pursuing new technologies, at the expense of existing ones needing roll-out.

1.4 Realistic assessments of technology development are essential; over-selling incremental improvements can lead to 'promise' fatigue in the minds of the public and investors.

1.5 Furthermore, future energy system projections should be examined by a range of scenario development methodologies [8]. Scenarios developed with public funding, or to support government policy, should be required to use fully transparent methods and models using verifiable real-world data to enable assumptions to be tested and to promote informed debate and stimulate innovation [9].

1.6 There is an urgent need for more research on the causes of risks associated with manufacturing and innovation in the accelerating transition to lower-carbon energy systems.

1.7 The total number of jobs in the energy sector is a result of new jobs created in pursuing net-zero minus those lost in the fossil-fuel extraction, production, processing, and supply sectors. It is the net total employed in the energy industry that is important, as it is this number which are contributing taxes and spending in the economy as a part of final demand [10].

2 What more can the Government do to encourage greater domestic supply chain investment in the energy industry by 2035, including through the Contracts for Difference scheme?

2.1 One of the most important risks to energy security is the changing policy and regulatory framework [2]. Discussion with senior industry stakeholders confirms that there has been significant impact on activities caused by frequent changing of relevant laws, regulation, and policy direction. As a regulated industry the energy sector must operate within this framework, therefore long-term stability is desirable. This is true for both renewable and non-renewable energy/fuel sources.

2.2 Long-term stability gives confidence to investors; the lack of access to capital is identified as the most significant risk to the energy industry as a whole.

2.3 The importance of any particular cause of risk may differ for each energy/fuel source (in total), for example, the risk of lack of access to capital is different for biogas and bioliquids, both of which differ significantly from tidal stream. The importance of any risk usually changes for each stage of the supply chain for any energy/fuel source.

2.4 Increased investment will be a component of economic growth if the design, manufacture, installation, maintenance, management, and other service sector components are located within the UK [11]. Any investment in industry is an opportunity to update plant and processes, thus increasing productivity and consequently growth [10].

2.5 Investment, both public and private, is conveniently measured by the international-agreed term gross fixed-capital formation (GFCF). As a proportion of GDP, GFCF in the UK is lower than in other G7 economies, and has been so for the past 40 years [12]. The causes of this long-standing problem constrain aspirations for increasing investment in UK, including in energy infrastructure. Suggestions addressing this problem include: fully reintroducing capital allowances, reversing the disincentives to fixed investment with long-term returns, increasing appropriately trained labour (see 1.1), coordination of supportive infrastructure, and a reducing policy uncertainty (see 2.1). A tool for tracking the demand for and supply of GFCF on an annual basis is the 7see framework and methodology [9,13].

2.6 With the above reasoning, we suggest that greater investment in the domestic supply chain requires better definition of long-term policy to give greater security to those considering investment (money, jobs) in the new energy system.

3 Does the UK have the supply chain capacity to deliver the required energy infrastructure by 2035, including an expanded electricity network?

3.1 Both the National Grid 'Leading-the-Way' [6] and the Climate Change Committee Balance Net-zero Pathway [14] are premised on approximately trebling the installed electricity generating capacity of the UK by 2050. This 'Scale of Challenge' [5] appears to be unrealistic given the risks outlined above.

3.2 There is an urgent need for more research on the causes of risks associated with manufacturing and innovation for the transition to a more renewables-focussed energy system [2]. The origin of the risk (UK or non-UK) varies across energy/fuel sources and along the stages of their supply chains. The origin of the risk affects what response is appropriate and who should be the custodian of that response.

3.3 Categorised as a manufacturing source of risk, insufficient capacity to construct sites, was identified as significant. This risk relates to the demands (scale, complexity, number) for constructing the extraction, processing, or energy conversion sites. An obvious manifestation of the risk is the low rate of development and progress of the Hinckley Point C plant [15]. As other risks, its importance varies between energy/fuel sources and along each supply chain.

3.4 We note that the UK's ability to construct energy infrastructure e.g. electricity transmission and distribution networks incurs much less risk (not zero, but lower).

4 To what extent would growing the domestic supply chain bolster UK energy security?

4.1 Quantifying the extent of any effect on UK energy security requires a transparent, data-driven, and robust measurement method [16]. Although many energy security indicators and assessment frameworks exist [17] none are used regularly. There are proposals of how to move forward with this question [3] and further development is needed.

4.2 The energy supply/demand balance must be maintained. Although reducing demand is as valid as expanding supply, it receives much less attention in its key role as a pillar of stable long-term energy security. Reproducing the characteristics of the cheap fossil-fuel-based energy economy with renewables will prove an enormous and perhaps impossible challenge. Intelligent and socially acceptable demand reduction must be included. So far, the various programmes aimed at reducing energy demand have mostly had little success, suggesting that we need a rethink of this vital element.

4.3 By treating 'Demand Reduction' as an additional fuel which delivers 'negative fuel' ('negafuel'), a particular level of energy services can be met at a lower volume of supply than would be possible in its absence. In this way, we can analyse Demand Reduction as any other fuel with a supply chain [18]. We define Demand Reduction as the group of activities, processes, and technologies usually termed energy efficiency, energy saving, energy conservation, demand-side response, and demand-side management. Demand Reduction incorporates both the use of devices and behaviour change – the alteration of the way society and individuals use energy – and accounts for the rebound effect [19]. The supply chain for Demand Reduction should in itself make an important contribution to the UK economy.

4.4 Our analysis showed that Demand Reduction is a middle-ranking fuel in terms of overall risk [20]. The most significant risks we identify include the difficulty of assessing and delivering potential energy savings, the rate of building construction at the highest energy efficiency standards, optimism bias, changing policy and regulation, and operational failure (both of technology and policy). The level of understanding required for effective policymaking necessitates additional and deeper analysis.

4.5 An unintended consequence of expanding the UK manufacturing capacity and capability for energy security (the re-shoring of economic activity) would increase GHG emissions from reduced imports whose emissions are currently not accounted for in the UK emissions totals [21].

5 What are the key concerns with respect to the availability of raw materials in the supply chain and how might those be addressed?

5.1 We are not contributing to this question.

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Appendix

Rank order of the causes of risk relevant to the UK, showing the dominant origin.

Rank	Cause of Risk	Category	Dominant origin
1	Lack of access to capital	Economic	Non-UK
2	Changing policy or regulatory framework	Political	UK
3	Significant public concern	Political	UK
4	Lack of vocational training of the local workforce	Skills	UK
5	Insufficient capacity to construct sites	Manufacturing	UK
6	Optimism bias	Innovation	UK
7	Lack of specialists in the local workforce	Skills	UK
8	Pollution event	Technical	UK
9	Operational failure	Technical	UK
10	Natural hazards	Environmental	UK
11	Only marginal improvements likely	Innovation	Non-UK
12	Unable to neutralise waste at decommissioning	Technical	UK
13	Insufficient capacity to manufacture system components or conversion devices	Manufacturing	Non-UK
14	R&D capacity or capability does not match the challenge	Innovation	UK
15	Quality of fuel source	Environmental	UK
16	Lack of a well-functioning market	Economic	Non-UK
17	Lack of public subsidy	Innovation	UK
18	Weak technology transfer environment	Innovation	Non-UK
19	Insufficient rate of improvement in, or lack of enforcement of, standards and codes	Political	UK
20	Price volatility	Economic	Non-UK
21	Lack of material substitutability	Innovation	Non-UK
22	Denial of permission to access sites	Political	UK
23	Lack of critical materials availability	Environmental	Non-UK
24	Difficult physical access	Environmental	UK
25	Insufficient rate of infrastructure construction	Manufacturing	UK
26	Specialist equipment unavailable	Technical	UK
27	Uncertain decommissioning costs	Economic	UK
28	Infrastructure failure	Technical	UK
29	Disputed land rights or resource ownership	Political	UK
30	Unable to agree a price for licence or permits	Economic	UK
31	Lack of basic education levels in the local workforce	Skills	UK
32	Lack of water availability	Environmental	UK
33	Lack of social stability	Political	UK

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