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An integrated systematic analysis of uncertainties in UK energy transition pathways

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HIGHLIGHTS

- Strategies to transition energy systems must contend with multiple uncertainties.
- Paper details approach to uncertainty analysis, linked to global sensitivity analysis.
- Key uncertainties strongly impact the costs and feasibility of required mitigation.
- An iterative approach between analyst and policy maker is required.

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ABSTRACT

Policy goals to transition national energy systems to meet decarbonisation and security goals must contend with multiple overlapping uncertainties. These uncertainties are pervasive through the complex nature of the system, the long term consequences of decisions, and in the models and analytical approaches used. These greatly increase the challenges of informing robust decision making. Energy system studies have tended not to address uncertainty in a systematic manner, relying on simple scenario or sensitivity analysis. This paper utilises an innovative UK energy system model, ESME, which characterises multiple uncertainties via probability distributions and propagates these uncertainties to explore trade-offs in cost effective energy transition scenarios. A linked global sensitivity analysis is used to explore the uncertainties that have most impact on the transition. The analysis highlights the strong impact of uncertainty on delivering the required emission reductions, and the need for an appropriate carbon price. Biomass availability, gas prices and nuclear capital costs emerge as critical uncertainties in delivering emission reductions. Further developing this approach for policy requires an iterative process to ensure a complete understanding and representation of different uncertainties in meeting mitigation policy objectives.

1. Introduction

1.1. Importance of systemic analysis of uncertainty in energy policy

Energy policy makers at the national government level are wrestling with a "trilemma" of challenges relating to energy decarbonisation, security of supply and rising energy prices (DECC, 2011). These policy challenges have multiple overlapping uncertainties, which are pervasive through the complex nature of the system, and the long term consequences of decisions (Lempert et al., 2003). This growing focus on uncertainty analysis in complex systems is mirrored at the international level for the needs of key energy and environmental decision makers (e.g., IPCC, 2014). The challenge of understanding, assessing and communicating uncertainties is magnified by the explosion in the range and sophistication in the models and analytical approaches used (Davies et al., 2014). In response to policy makers' difficulties in assessing uncertainties, modellers have repeated calls to improve the frequency, sophistication and transparency of uncertainty analysis in computational modelling of energy, environmental and economic interactions (Morgan and Small, 1992; Kann and Weyant, 2000; Risbey et al., 2005; Pfenninger et al., 2014; Usher and Strachan, 2012).

There is a long track record of energy models underpinning major energy policy initiatives, producing a large and vibrant research community and a broad range of energy modelling approaches (Jebaraj and Iniyan, 2006). Modelling collaborations have been an important tool to benchmark models, addressing specific analytical questions (van Vuuren et al., 2006) and advancing the

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state-of-the-art in modelling (Hourcade et al., 2006). Throughout this long track record there has been a tension between policy makers who need to make robust decisions under pervasive uncertainties, and modellers whose analytical outputs are designed to produce insights (Huntington et al., 1982).

The most common approach for dealing with uncertainty in large-scale energy modelling is local sensitivity analysis on key inputs to which a model is expected to be most sensitive (Saltelli and Annoni, 2010). However, such approaches are limited as they fail to capture the importance and impact of multiple uncertainties. This paper describes a novel approach using an innovative UK energy system model, ESME (Pye et al., 2014b), which characterises multiple uncertainties via probability distributions and propagates these uncertainties to explore trade-offs in cost effective energy transition scenarios. A global sensitivity analysis is then undertaken to explore the uncertainties that have most impact in the long term mitigation pathways.

1.2. Application to UK decarbonisation pathways

The international scientific and governance communities have reached a consensus that climate change presents a severe barrier to future human well-being and livelihoods (IPCC, 2014). In response, the UK was the first G20 country to legislate GHG reduction targets, of at least −34% by 2020 and exponentially declining to −80% by 2050, relative to a 1990 baseline (HMG, 2008). A range of policy mechanisms (DECC, 2011) are now in place to put the UK on a path to meeting this long-term stringent target, with the setting of five-year carbon budgets by the independent governmental advisory body (CCC, 2008).

Although the UK is one of the few countries on track to meet its GHG targets, the remit of UK energy and environmental policy has been substantially aided by long term structural reform e.g., the dismantling of the nationalised and unionised power sector, the continued restructuring of the economy from industry to services and the impact of the financial crisis and subsequent recession. As the UK (similarly to other OECD economies) recovers from recession and hence pressures on emissions continue to grow, the debate over strategies and costs of long term decarbonisation under a range of national and global uncertainties is becoming ever more heated (Ekins et al., 2011).

In its recent review of the 4th Carbon Budget (CCC, 2013), the Committee on Climate Change (CCC) reiterated the need for early action to reduce emissions out to 2030, to ensure the UK was on a pathway to meeting the longer term 2050 target. It concluded that the budget should be kept at the level provided in its original advice to Government (CCC, 2010), rather than tightened, but that the aim should still be to achieve early decarbonisation of the power sector, in addition to strong action across other sectors. The CCC deem this critical if the UK is to follow a cost-effective path towards decarbonisation, and avoid the additional costs associated with delayed action.

However, key uncertainties exist around the delivery and cost of the 4th Carbon Budget and 2050 target, such as economic growth and structural change, delivery capacity (including financing), technology costs and behavioural change. The uncertainties are of fundamental importance, given the large investments required to fund this transition, and because these investment decisions will result in long term consequences around the direction of the transition. The CCC (2013) estimate that total capital costs of scenarios to decarbonise the power sector to an intensity of 50 g CO_2/kWh by 2030 could be of the order of £200 billion cumulatively.

1.3. Research aims and layout of the paper

The objective of this paper is to explore the impact of technological and economic uncertainties critical to delivery of a lower carbon energy system. The task is performed using an energy systems model (ESME) which provides a framework for the systematic analysis of multiple uncertainties on target delivery and technology pathways out to 2050 (see Section 2). This assessment of the complex and interacting energy system is strengthened by a linked global sensitivity analysis which identifies key and non-influential uncertainties affecting the cost-effective pathway. Section 3 discusses selected results focusing on how uncertainties impact on achieving emission reduction targets, the importance of technologies and fuels in delivering targets, and the uncertainties that are revealed as most critical in the transition to a low-carbon energy system. In Section 4, we discuss the key insights, and in Section 5, how understanding the impact of uncertainty on the system is critical for policymaking, and on the opportunities for improved modelling in the structuring, assessment and communication of key uncertainties.

2. Methods

2.1. Uncertainty in energy systems models

Since 2003, many energy system modelling studies have been undertaken to support UK energy and climate strategy development. Most studies have been deterministic in approach, capturing the range of uncertainty using simple scenario sensitivity analysis on parameters (DTI, 2003; Strachan et al., 2009; AEA, 2011). While arguably playing a critical role in supporting the development of UK long term strategy, many of these studies have not addressed the uncertainties surrounding the transition to a low carbon system in an integrated and systematic manner. Usher and Strachan (2012) argue that applying a deterministic methodology to a complex and multi-faceted area of strategy development that is inherently uncertain is problematic. They highlight three key problems with simple sensitivity analysis – (i) the probability of an input value cannot be quantified, (ii) disparate sensitivity scenarios make policy insights more difficult to determine and (iii) the cost of uncertainty is unknown.

The strategies informed by such modelling have to consider uncertainties that fall into questions of ‘post-normal science’ (Funtowicz and Ravetz, 1990), where both decision stakes and uncertainty levels are high (Keirstead and Shah, 2013). The decisions made about energy systems have significant consequences (stakes are high) while the complexity of the system makes it difficult to determine the outcomes of different decisions (uncertainty is high). While the strategic decision has been taken to transition to a low carbon economy in the UK, there remain a multitude of decisions relating to investment that need to be considered, and the policies to incentivise these investments.

In this paper, a probabilistic approach is used, combined with an integrated systematic sensitivity analysis to explore the effects of parametric uncertainty on the model outputs. Keirstead and Shah (2013) argue that global sensitivity analysis techniques should be used in conjunction with uncertainty analysis, to help decision-makers gain a robust understanding of system behaviour. Saltelli et al. (2008) define sensitivity analysis as the study of how uncertainty on a model output can be apportioned to different sources of uncertainty in the model input, whereas uncertainty analysis is concerned with quantifying uncertainty in the model output. In effect, global sensitivity analysis seeks to answer questions around what are the most important uncertainties in the system.