Energy Policy 73 (2014) 575–586

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

The uncertain but critical role of demand reduction in meeting long-term energy decarbonisation targets☆

Steve Pye*[,1], Will Usher[1], Neil Strachan[1]

UCL Energy Institute, University College London, 14 Upper Woburn Place, London WC1H 0NN, United Kingdom

HIGHLIGHTS

- Price driven demand reductions are a critical mitigation option.
- Such options are crucial for cost-effective transition to a low carbon energy system.
- Uncertainty does not fundamentally undermine this conclusion.
- Focus of demand reduction should particularly be on transport sector.

ARTICLE INFO

Article history:
Received 27 February 2014
Received in revised form
3 May 2014
Accepted 15 May 2014
Available online 21 June 2014

Keywords:
Energy demand response
Climate change mitigation
Energy systems modelling

ABSTRACT

Endogenous demand responses for energy services, resulting from changing prices, have long been characterised in energy systems models. However, the uncertainty associated with such demand responses, modelled through the use of price elasticities, has often been ignored. This is problematic for two key reasons – elasticity factors used in models are highly uncertain due to the limited evidence base, while at the same time, demand response has been observed as a critical mechanism for meeting long term climate mitigation targets. This paper makes two important contributions for improving the understanding of the role of price-induced demand response. Firstly, it attempts to address the problem of unsatisfactory elasticity input assumptions by undertaking an up-to-date review of the literature. Secondly, the role of demand response under uncertainty is assessed using a probabilistic approach, focusing on its contribution to mitigation. The paper highlights that demand response does play a critical role in mitigation, ensuring a more cost-effective transition to a low carbon energy system. Crucially, the uncertainties associated with price elasticities do not weaken this finding. The transport sector is the driver of this demand response leading to important implications for policy and the focus of demand side interventions.

1. Introduction

The challenge of meeting medium to long term decarbonisation targets cost-effectively not only requires the large scale uptake of low carbon technologies and fuels but also behaviour change. The role of behaviour change, alongside technological solutions, has been an emerging theme of many international and national modelling assessments. In a review of low carbon transition modelling analyses, Strachan et al. (2008) conclude that low carbon *scenarios are technologically feasible given expected progress in low-carbon measures and the behavioural change required to adopt technologies and complement them with emissions reductions*. This conclusion emerges strongly from other high profile international modelling studies such as the Energy Technology Perspective (ETP, IEA, 2012) and the Global Energy Assessment (GEA, Nakićenović, 2012). The ETP highlights the important role of modal shift in the transport sector and preferences for vehicle type, and the impacts of behaviour on energy use in residential buildings. The GEA highlights the need for a change in culture and lifestyles as part of the wider strategy for a more sustainable, low carbon energy system.

Energy systems models (ESMs) have emerged as an important energy modelling approach for exploring pathways for meeting long term decarbonisation targets. Nowhere has their systematic use for national strategy development been as well demonstrated as in the UK. Since 2000, following the landmark publication by the RCEP (2000), proposing a 60% national decarbonisation goal, energy systems models have provided supporting analysis to each

☆An earlier version of this paper was submitted to and accepted at the 33rd edition of the International Energy Workshop (IEW), Beijing, 4–6 June 2014.

* Corresponding author.
E-mail address: s.pye@ucl.ac.uk (S. Pye).
[1] Tel: +44 203 108 5989.

http://dx.doi.org/10.1016/j.enpol.2014.05.025

energy strategy (Strachan et al., 2009), strategies which have led to the establishment of a legislative act mandating a carbon reduction target of 80% reduction in GHG emissions in 2050, relative to 1990 levels, and a set of ambitious mid-term carbon budgets (DECC, 2011). All modelling analyses have highlighted the affordability of ambitious low carbon targets but also the requirement for investment in a diverse mix of technology options and the requirement for behavioural change (Ekins et al., 2013).

One feature often used to represent a key aspect of behaviour change in ESMs is price elastic demands. This allows for demand for energy services to be endogenously determined based on changing prices for those services. In the case of climate targets, investment in low carbon technologies and fuels drives up prices for energy services, leading to reductions in demand. The role of demand reduction under carbon targets has been identified as critical for delivering ambitious mitigation targets, particularly in sectors where technical supply-side measures are higher cost or their potential is limited. Anandarajah et al. (2009) estimated demand reductions of up to 25% for residential and industrial sectors under the UK's 80% reduction target in 2050. A recent UK modelling study suggests that the technical feasibility of meeting the 80% decarbonisation goal would not be possible without demand reduction (AEA, 2011). Chen et al. (2007) underline the importance of demand reduction in their analysis of mitigation costs in China, estimating a resulting 60% reduction in marginal abatement costs in 2020. Other analyses also support the importance of demand reductions in climate mitigation both in the UK (AEA, 2008), and globally (Kesicki and Anandarajah, 2011). Given the criticality of demand reductions to a low carbon system transition, assumptions need to be as robust as possible.

However, two key problems are associated with the modelling of demand response in ESMs. Firstly, elasticity assumptions have often been poorly defined, unclear what they represent (short or long run, final energy demand or energy service demand), been subject to limited review, and taken from a limited empirical evidence base. Secondly, as a result, these model input assumptions are highly uncertain. In this paper, the characterisation of price-driven demand response is improved via an up-to-date review of the literature, and innovative probabilistic implementation of price elasticity uncertainties in the UK Energy Systems Modelling Environment (ESME) model. The improved characterisation of demand response in ESME allows for more robust insights into its role across different sectors and the trade-offs with supply-side options (including technical energy efficiency measures), and the impact of uncertainty associated with demand side response in a systems context.

Section 2 provides a review of the literature, briefly examining the role of demand response as highlighted in recent mitigation modelling analyses, and then focuses on a review of the literature on price elasticity assumptions. It then describes the energy systems modelling framework used for exploring demand response, the ESME model, and the approach to modelling price elasticities. Section 3 presents the results of the analysis, followed by a discussion of the insights from the analysis in Section 4. Finally, Section 5 discusses the implications of the research for policy and outlines further research needs.

2. Material and methods

2.1. Literature review: price elasticities for energy service demands

2.1.1. The challenges of implementing demand response in ESMs

The strength of energy systems models (ESMs) is their integrated approach to modelling of energy supply and demand, providing rich detail on the technologies and fuels that will be required to meet future energy demands under a range of possible scenarios. Well known models, such as MARKAL/TIMES (Fishbone and Abilock, 1981; Seebregts et al., 2002) and MESSAGE (Messner and Schrattenholzer, 2000), use linear programming to assess cost-optimal mixes of technologies, based on technical costs associated with energy system development. The focus of such models on supply-side representation draws attention to the deficiencies in the representation of demand side and behavioural factors, as highlighted by Hourcade et al. (2006) and Schafer (2012).

However, the inclusion of price elastic demands, a key feature of representing price-driven behaviour, has long been a feature of ESMs. First implemented in MARKAL models by Loulou and Lavigne (1996), it is now a feature of most ESMs (Bhattacharyya and Timilsina, 2009), and is described in more detail in Section 3. It allows for the modelling of endogenous trade-offs between investment in low carbon technologies and fuels, including end use sector energy efficiency and conservation, and the loss of welfare associated with reducing demand (due to price increases, not through voluntary reductions). Most ESMs use own price elasticities, which measure the percentage change in the quantity demanded of a given energy service as a result of a percentage change in its price. Cross price elasticities, on the other hand, measure the change in quantity demanded of a given energy service *X* as a result of a change in price of energy service *Y*. The most common application of cross-price elasticities relates to transport demand; however, few ESMs explicitly use cross-price elasticities (Schafer, 2012).[2]

Determining own price elasticities, the focus of this paper and their associated uncertainty for use in ESMs is challenging, as noted by Anandarajah et al. (2009) and Sorrell et al. (2009). A key difficulty arises due to the type of elasticity factor required. Sorrell et al. (2009) usefully differentiates between the following elasticity types (where *D* is the demand, *ES* is the energy services, *P* is the price) – (1) elasticity of *D* for *ES* with respect to *P* of *ES*, (2) elasticity of *D* for *ES* with respect to *P* of energy, and (3) elasticity of *D* for energy with respect to *P* of energy. For ESMs, values for (1) tend to be required as demands are usually specified as energy services while much of the literature focuses on (2) and (3). In addition, studies often analyse short run elasticities while for ESMs undertaking longer term analysis, long run elasticities are more appropriate, to represent the effect of price changes over a longer period (5–10 years), allowing for more radical shift in choices e.g. change in technology stock.

Secondly, the range of estimates for different energy demands is large, with many of the studies using different estimation approaches (Sorrell and Dimitropoulos, 2007). Differences also result from geographic location of studies, and the types of demands being assessed. For example, transport sector elasticities can vary depending on trip purpose, income group, spatial context (urban versus rural), and choice of alternatives (Litman, 2013). Thirdly, elasticity estimates are based on historical observation using econometric approaches, capturing market imperfections and policy initiatives. Optimisation models however are forward looking, assume perfect market conditions and are often run with policies omitted (Boonekamp, 2007). Finally, and related to the above point, models only provide a partial representation of the 'real world'. The observed relationship between price and demand may be based on a range of choices that may not be present in the model. For a given elasticity, the demand response in a poorly

[2] The implementation of cross-price elasticities is described in the MICRO version of MARKAL/TIMES models (Seebregts et al., 2002) although no papers in the literature describe this model implementation for analysis.