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The evolution of electricity demand and the role for demand side participation, in buildings and transport

John Barton [a], Sikai Huang [b], David Infield [b], Matthew Leach [c], Damiete Ogunkunle [c], Jacopo Torriti [d], Murray Thomson [a,*]

[a] Centre for Renewable Energy Systems Technology, Loughborough University, Loughborough, LE11 3TU, UK
[b] Institute of Energy and Environment, University of Strathclyde, Glasgow, G1 1XW, UK
[c] Centre for Environmental Strategy, University of Surrey, Guildford, GU27XH, UK
[d] School of Construction Management and Engineering, University of Reading, Reading, RG6 6AY, UK

HIGHLIGHTS

- ► Evolution of UK electricity demand along 3 potential low carbon Transition Pathways.
- ► Electrification of demand through the uptake of heat pumps and electric vehicles.
- ► Hourly balancing of electricity supply and demand in a low carbon future.
- ► Demand side participation to avoid low capacity factor conventional generation.
- ► Transition Pathways to an 80% reduction in UK operational CO_2 emissions by 2050.

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ABSTRACT

This paper explores the possible evolution of UK electricity demand as we move along three potential transition pathways to a low carbon economy in 2050. The shift away from fossil fuels through the electrification of demand is discussed, particularly through the uptake of heat pumps and electric vehicles in the domestic and passenger transport sectors. Developments in the way people and institutions may use energy along each of the pathways are also considered and provide a rationale for the quantification of future annual electricity demands in various broad sectors. The paper then presents detailed modelling of hourly balancing of these demands in the context of potential low carbon generation mixes associated with the three pathways. In all cases, hourly balancing is shown to be a significant challenge. To minimise the need for conventional generation to operate with very low capacity factors, a variety of demand side participation measures are modelled and shown to provide significant benefits. Lastly, projections of operational greenhouse gas emissions from the UK and the imports of fossil fuels to the UK for each of the three pathways are presented.

1. Introduction

Foxon (this issue) describes the development of a set of three narratives outlining alternative pathways towards a low carbon economy in the UK. These are: a market-led pathway named Market Rules (MR); a government-led pathway known as Central Coordination (CC); and a civil society-led pathway, Thousand Flowers (TF). The pathways are politically and socially distinct, but all lead to a high degree of electrification, particularly in the transport and heating sectors, and thus the project has focused on the evolution of the electricity sector. In traditional scenario development for energy systems or climate change mitigation, a distinction is frequently made between thinking about possible changes on the 'demand-side' and the 'supply-side'. The former revolves around the lifestyles and consumption habits of the population, the stock of energy-using appliances, buildings and vehicles, and the fuel choices made within demand sectors or by consuming groups, leading to aggregate quantification of fuel and electricity end-use. On the supply-side, scenarios require analysis of the supply chains needed to deliver the requisite fuels and electricity to the point of use. This typically involves consideration of both infrastructures and primary resource inputs.

The Transition Pathways project has taken a slightly different approach. Whilst initial efforts followed the traditional model of

* Correspondence to: Senior Lecturer in Electrical Networks and Systems, CREST (Centre for Renewable Energy Systems Technology), School of Electronic, Electrical and Systems Engineering, Holywell Park, Loughborough University, Loughborough, LE11 3TU, UK. Tel.: +44 1509 635344.
E-mail address: M.Thomson@Lboro.ac.uk (M. Thomson).

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demand side analysis followed by supply side, the primary focus here has been on interrogating and understanding the interplay between the two. The need for this has been driven by two underlying tenets: first that the inherent variability of renewable energy sources leads to a requirement for much greater flexibility on the demand side and second that a significant proportion of this generation may be in the form of small scale installations at consumer level. Thus the traditional distinctions between the demand and supply sides become blurred: consumers may become 'prosumers'—producing electricity onsite to meet at least some of their own demand and potentially exporting any excess. The required flexibility may come partly from this local generation, but in the main relies on consumers' willingness to change their consumption patterns. Opportunities for larger consumers to benefit economically by adjusting their demand patterns in response to price or other signals are already widely established in electricity markets, through half-hourly metering, time of day pricing and contracting of demand-response by the system operator. However there are potentially large and additional benefits to be realised from engaging small consumers, and with this in mind, the Transition Pathways project has focused particularly on the residential sector and personal transport.

The project has thus adopted an integrated process for developing pathways, following the steps below:

1. Development of 'narrative' descriptions of alternative pathways, in which the above changes take place to varying degrees (see Foxon, this issue).
2. Interpretation of the narratives into quantified models of energy demand on an annual average basis for the years from 2010 to 2050, including in particular increased electrification of heating and transport.
3. Interpretation of the narratives and annual demands to provide quantitative models of electricity supply and associated infrastructure, on an annual average basis.
4. Assessment of the proportion of generation that would be located at the consumer level.
5. Determination of prospective hourly demand and generation profiles based on the above, and including in particular an analysis of likely driving and electric vehicle (EV) battery charging patterns.
6. Iterative estimation of electricity supply and infrastructure needs required to maintain hourly balancing with the projected demand profiles, and with consideration of plant capital costs and operational carbon emissions.
7. Assessment of the potential for greater demand side participation in managing grid balancing.

As noted above, the project has followed an integrated and iterative process, but for the purposes of presentation, steps 3, 4 and 6 are reported by Barnacle et al. (this issue), while steps 2, 5 and 7 – the evolution of electricity demand – are the focus of the present paper. The next section provides an overview of step 2: modelling the use of fuels and electricity by the main sectors of the economy of the UK over the period to 2050, in terms of annual averages.

The paper then describes the application of the Future Energy Scenario Assessment (FESA) model to examine system energy balancing on an hourly time basis as the annual demands described above evolve up to 2050. Analysis of the resulting peak and base load patterns in relation to the available generation detailed by Barnacle et al. (this issue), serves to quantify the grid balancing challenge. The paper concludes with an initial assessment of the role of demand side participation in addressing this challenge, particularly with regard to the potential for time shifting of thermal demand in the built environment and scheduling of EV battery charging.

2. Annual demand quantification from pathways

A bottom-up, sectoral approach is taken, aggregated to provide overall trends in annual demand for the principal end-use fuels and electricity. As noted above, particular attention is given to residential energy use and private passenger transport, reflecting interest in the possibilities for decentralised generation and greater consumer demand response down at the smallest level of consumption. For residential energy use, a model of energy service demands is combined with a building stock model, and changes in demand are simulated as existing buildings are retrofitted with energy efficiency measures and as new buildings are erected with increasingly high thermal performance. The stock of energy-using appliances and heating systems is modelled, reflecting the characteristics of the different Pathway narratives. For passenger transport, detailed analysis of UK car use, including time and duration of travel, is undertaken through a probabilistic simulation model calibrated to the UK Time Use Survey (Ipsos-RSL and Office for National Statistics, United Kingdom Time Use Survey (2000) and the (Department for Transport, National Travel Survey (2002–2008). For the service sectors, industry and other transport modes, electricity use is projected based on the results of existing modelling by the UK's Department for Energy and Climate Change (DECC, 2010), tailored to match the trends described in the project's Pathway narratives.

2.1. Electricity demand for space and hot water heating

For domestic energy use, simulation models of energy service demand and building stock were developed at the University of Surrey. The models follow the broad structure of the DECC carbon calculator (DECC, 2010) but incorporate finer resolution of technical mitigation measures and their applicability, and allow representation of changes in end-user behaviours. Changes in the estimated demand over time reflect improvements to the building stock resulting from retrofitting and new build, following the steps outlined in the following sections.

2.2. Existing buildings

As a baseline, space and water heating demands for existing households before the introduction of energy efficiency measures are derived as a product of household number projections from 2000 to 2050, assuming a demolition rate of 0.0762% per yr (Kannan al. (2007), Kannan and Strachan (2009), and the average space and water heating demand for existing homes of 32.73 and 13.37 GJ/yr per household, respectively (Kannan and Strachan (2009); Kannan al. (2007)).

Savings in space heating are estimated based on the projected uptake of conservation measures for wall, cavity, floor and loft insulation as well as replacement of single with double glazing (Element Energy, 2009; Energy Efficiency Partnership for Homes (2008)). We assume that measures are typically applied in 'packages' and assume wall insulation is applied first, followed by loft, floor and then improved glazing. The pace and saturation levels for the uptake of measures were adjusted for each of the three pathways to reflect the narrative assumptions.

For water heating load calculation purposes, the uptake for water tank insulation is derived from the Energy Efficiency Partnership for Homes (2008). Finally, the residual electricity hot water and space heating demand are calculated.