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The implications of heat electrification on national electrical supply-demand balance under published 2050 energy scenarios

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ABSTRACT

Published UK 2050 energy scenarios specify a range of decarbonised supply side technologies combined with electrification of transportation and heating. These scenarios are designed to meet CO_2 reduction targets whilst maintaining reliability of supply. Current models of the UK energy system either make significant assumptions about the role of demand side management or do not carry out the analysis at sufficient resolution and hence determining the impact of heat electrification on the reliability of supply of the scenarios is not possible. This paper presents a new model that estimates national supply and demand, hour-by-hour. Calculations are based on 11 years of weather data which allows a probabilistic assessment of deficit frequency throughout the day. It is found that achieving demand reduction targets are far more important than meeting electrification targets and that significant adoption of CHP is most likely to deliver a viable energy future for the UK.

1. Introduction

The energy future of the UK is uncertain. The rising dependency on foreign imports of oil and gas is escalating fears of energy security whilst environmental policy and the Climate Change Act are pushing for changes in the way in which energy services are delivered. A number of energy scenarios that envision the UK's energy infrastructure in 2050 have been published, all of which could potentially meet the UK's commitment to an 80% reduction in CO_2 emissions. Evident in the majority of these scenarios and in the wider political debate, is a growing consensus that electricity will play a central role in the UK energy system of the future [1–7]. Common themes are an increasing proportion of electric vehicles and the replacement of gas driven technologies for heat pumps to provide space heating in buildings, both of which can be decarbonised by deploying other technologies such as solar PV (photovoltaic), wind farms and CCS (carbon capture and storage).

A central challenge for these scenarios is the delivery of electrified space heating. Peak heating demands can drive the power supplied by the gas networks up to 300 *GW*, six times greater than peak power on the electricity system. Currently gas storage acts as a buffer between supply and demand enabling the gas network to cope with these peaks, an electricity network, however, requires instantaneous supply-demand balancing to avoid blackouts. Only recently has the electrification of heating been considered as having a significant impact on maintaining the security of electrical supply [8] and high resolution modelling techniques are needed to investigate what the implications are for the assumptions on which scenarios are based.

EnergyPlan is a widely used system model, that incorporates transport and heating electrification hour-by-hour and has been applied predominately within Denmark [9–14]. The model has been applied to Estonia, Lithuania and China [15–17], but not the UK. The energy system of Denmark is of a different composition to the UK, apart from the significantly lower electrical demands, 60% of heating is supplied via district heating and 80.5% of this heat is produced by CHP (Combined Heat and Power). See Connolly et al. [18] for a review on energy system modelling tools.

High resolution analysis for the UK was conducted by the 'TP (Transition Pathways) to a Low Carbon Electricity Economy' research group using the 'FESA' (Feasibility of Energy Scenario Assessment) model, developed by Barton et al. [19]. FESA is more detailed than the MARKAL (MARket ALlocation model) [20], which considers only 20 approximated 'timeslices' within a specific version of MARKAL (Temporal MARKAL) and is one of a minority of energy system models that incorporates transport and heating

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Nomenclature

SHED	smart household energy demand model
DECC	department of energy and climate change
DECC:CCS	DECC carbon capture and storage 2050 scenario
TP	transition pathways
TP:CC	TP central coordination 2050 scenario
CHP	combined heat and power
CCGT	combined cycle gas turbine
MIDAS	met office integrated data archive system
HadCET	Hadley centre central England temperature
MAWS	met office marine automatic weather station
DSHD	delivered space heating demands
S	historic space heating demand
T_{NH}	scenario water heating demand
T_{NH}	no heating temperature
D_H	degree hours
p_{sp}	space heating demand profile
f^{HP}	fraction of households with heat pumps
FESA	feasibility of energy scenario assessment model
DECC:Nuc	DECC nuclear 2050 scenario
DECC:Renew	DECC renewable 2050 scenario
TP:MR	TP market rules 2050 scenario
TP:TF	TP thousand flowers 2050 scenario
CCS	carbon capture and storage
DSM	demand side management
BADC	British atmospheric data centre
RAL	Rutherford appleton laboratory
HDH	heating degree hour
S_{sc}	scenario space heating demand
E_{sc}^{HP}	scenario heat pump demand
T_s	smoothed temperature
n	numbers of hours in the year
$S^p(t)$	hourly *unrestricted* DSHD
COP^{HP}	coefficient of performance of heat pumps

electrification simultaneously with a variable renewable supply, using a time step of 1 h.

FESA is driven using 12 months of weather data and assumes households will play a significant role in balancing through DSM (demand side management). A limitation of the model is the assumption that the space heating demand profile over a 24 h period in all households will be constant (called a 'restricted profile'). This implies that households will be required to heat throughout the day rather than the traditional timing of morning and evening and was treated this way in order to simplify the task of balancing supply and demand [19]. This is a significant assumption which results in the FESA model under-representing peak hourly electrified heating demands and hence is likely to underestimate periods of supply deficit.

In order to evaluate the susceptibility of energy scenarios to supply-demand deficits, a new model called 'SHED' (Smart Household Energy Demand) is presented. Although based on similar modelling principles to that of FESA, SHED does not make any assumptions about the role of future DSM and hence can be used to investigate the implications of space heat electrification on balancing supply and demand by estimating the probabilities of timing and magnitude of deficit periods. The model implements a number of other improvements over those used in FESA, the most notable being the treatment of weather which is extended over 11 years and uses a greater degree of localisation. The paper presents the model and applies it to 6 published UK energy scenarios in order to evaluate the implications of heating electrification on reliability of supply and the role of energy demand reduction in the future.

2. Selection of energy scenarios

Energy scenarios are used to map out mixes of different energy supply methods and levels of demand and although it is unlikely that any of these will be realised in the future, they represent options that are able, at least on paper, to deliver the UK's 80% on CO_2 emissions reduction targets. By selecting a number of scenarios to investigate through modelling, a range of heat electrification levels and generation mixes can be explored, allowing more general insights to be gained.

In 2010, the DECC (Department of Energy and Climate Change) published the 2050 Pathways Analysis: 10 of the 16 sub-scenarios specify ≥25% of heating to be electrified and 5 specify ≥80% [5]. 3 of the scenarios describe significantly different futures and are used here in the analysis: "Higher renewables, more energy efficiency", abbreviated here to *DECC:Renew*; "Higher nuclear, less energy efficiency", *DECC:Nuc*; and "Higher CCS, more bio energy", *DECC:CCS*. Research by the TP (Transition Pathways) research group [1,2] developed an alterative set of scenarios, from which the other 3 used in this analysis are taken: a market led pathway, called "Market Rules", *TP:MR*; a government led pathway, "Central Coordination", *TP:CC*; and a society led pathway, "Thousand Flowers", *TP:TF*.

Fig. 1 compares the annual energy demand in the building related energy categories for each of the 6 scenarios. Note that in the DECC scenarios 48–90% of heating demand is electrified compared to between 24.5% in TP:TF and 76.2% in TP:CC [3].

Fig. 2 depicts the generation capacities for each scenario. TP:CC and TP:MR have the greatest diversity in generation, the latter having the greater total capacity of ~163*GW* due to increased onshore wind, coal (with CCS) and unabated CCGT (Combined Cycle Gas Turbines).

TP:TF is heavily reliant on CHP district heating systems (52.5*GW*), which produce power simultaneously with heat: >70% of the current installed generating capacity (2013, 74.7*GW*). *TP:TF* also assumes substantial capacity of solar PV (photo-voltaic) and onshore wind generation with a small contribution from dispatchable generators.

DECC:Nuc is dominated by nuclear generation (75*GW*), with a small contribution from onshore and offshore wind generation and has the second smallest total generation capacity of ~100*GW*. *DECC:CCS* assumes the lowest total generation capacity of ~97*GW*, with ~42*GW* supplied by CCS fitted coal and CCGT generators, the remaining generation capacity is made up of wind, nuclear and hydro. Finally *DECC:Renew* assumes ~138*GW* total generation capacity, of which ~82*GW* is supplied by onshore and offshore wind, 14*GW* of solar PV and only 14*GW* of dispatchable generation (~10% of total capacity).

These 6 scenarios represent a broad range of generation capacities and technologies, together with a range of assumptions regarding the electrification of space heating. Throughout the paper, relevant parameters are compared to describe important features of the modelling that underpin the analysis.

3. Modelling overview

SHED is a hybrid top-down national supply-demand model with a bottom-up household demand and DSM (Demand Side