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Possible effects of future domestic heat pump installations on the UK energy supply

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ABSTRACT

This research study investigates the effects of the large-scale installation of domestic heat pumps on the UK electricity supply over the short to medium term. A BREDEM-based dwelling energy model, incorporating a model of heat pump performance, is enhanced for the effects of varying monthly temperatures. Data from the English Housing Survey (2007) are analysed using this model to estimate electricity consumption to 2020 and 2050, and simulate scenarios for replacing existing heating systems by ground or air source heat pumps. The type of heat pump (ground or air source) is determined by dwelling plot dimensions data from the EHS. Modelling results for 2020 showed that a policy of replacing the heating systems with the highest emissions could reduce or at least minimise the increase in electricity consumption and carbon emissions. Results for 2050 showed that replacement of some 80% of current gas-fired systems would enable the UK to meet its target of 80% carbon emissions reduction in this sector when accompanied by simultaneous decarbonisation of the electricity supply. These results provide some support for the UK government's policy of subsidizing heat pump installations through the Renewable Heat Incentive payments while indicating that meeting emission targets requires far greater adoption of these systems than current ambitions.

1. Introduction

1.1. Background to this study

Current policy-making on energy in the UK is faced with some significant challenges: the first is the "gap" in the UK electricity supply in the order of 22 GW, which will occur when the most of the current "fleet" of nuclear power stations are decommissioned in the period up to 2025, reducing the UK's generating capacity by about 10 GW out of 85GW [1] and when a further 12 GW of fossil fuel-fired power stations are forced to close because of the requirements of the Large Combustion Plant Directive (LCPD), which regulates emissions of sulphur and nitrogen oxides [2]; the second is the need to 'de-carbonise' the UK electricity supply as part of the requirements of the 2008 Climate Change Act [3] for an 80% reduction in carbon dioxide emissions; a third is the requirement to generate 20% of the UK's heat requirements from renewable sources by 2020, [4] under the requirements of Article 4 of the European Renewable Energy Directive (2009/28/EC): lastly, the fall in output which means that the UK has once again become an importer of natural gas [5].

To meet the latter requirement, the UK Department of Energy and Climate Change put forward a scheme to subsidize the production of heat from renewable resources, the Renewable Heat Incentive (RHI), for which the initial proposals were that owners, domestic or non-domestic, of newly-installed air and ground source heat pumps would be paid a subsidizing rate per nominal – 'deemed' – kilowatt hour [6]. With a change of government in 2010, these proposals have been revised to exclude domestic users from receiving the output-related subsidy but instead to receive a one-off payment, the "Renewable Heat Incentive Premium Payment" (RHPP) for which both main categories of heat pumps will be eligible [7], with the original RHI proposal still under consideration for residential systems. While domestic heat pumps are not the only system types eligible for these payments, the possible effects of a considerable increase in the number of electrically-powered systems are worthy of analysis, both for their effects on the UK electricity supply and for their contribution to carbon emission reduction.

The paper reports on research carried out as part of a 3.5 year project funded by the Engineering and Physical Science Research Council (Grant No. CASE/CNA/06/82) to assess the potential of ground source heat pumps in reducing

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energy-related carbon emissions from UK housing in a changing climate.

1.2. Study objective

Given the challenges facing the UK electricity generation system and the possible disruptive effect of the installation of heat pumps on heating systems in UK housing, the objective of this study is to estimate the effect of the possible numbers of heat pumps on the UK electricity supply, both in terms of extra loads and also in terms of meeting the UK targets for carbon emission reduction. This is of concern, not only because of the shorter term electricity supply problems but also because of the necessity of replacing the current monoculture of gas-fired systems in UK dwellings in order to take advantage of the decarbonisation of the UK electricity supply. The manufacturing of a large number of heat pump systems will involve substantial embedded carbon, which must also be considered. Further aspects of the conversion to heat pumps which will have an impact on electricity demand is the possibility of the adoption of heat pumps that provide space cooling as well as heating – "reversible" heat pumps – and of the possible installation of photo-voltaic systems to balance this extra summer-time load.

This study consists of the analysis of possible heat pump deployments, which, along with rules as to which dwelling types systems are to be applied and other parameters, have been termed '*scenarios*'. This employs the typology described by Dixon [8], who defines this type of 'future thinking' as "*use[ing] imagination to consider possible future alternatives*", though the term '*technical scenario*' distinguished by Eames and McDowall [9] as "*emphasis[ing] the technical feasibility and implications of different options, rather than explore how different futures might unfold*" might be more appropriate as this study does not attempt to indicate the path that will be taken to reach any of the scenarios, a characteristic which Dixon attributes to other 'future thinking' types such as '*roadmaps*', '*transitions*' and '*pathways*'.

Those proposed do not encompass all the various social, technological and political aspects of the future of energy use in the UK included in the UK Government's Foresight report [10]. This suggested four scenarios, with slightly fanciful titles, encompassing visions where regions are autonomous in energy generation, "Resourceful Regions"; where fossil fuel continues to be dominant along with carbon capture and storage, "Carbon Creativity"; where energy efficiency, demand reduction – of all kinds, and distributed generation are most significant, "Sunshine State"; and where large scale renewables – the Severn Barrage, off-shore wind and north African solar – are predominant, "Green Growth". These have been superseded to some extent by the legal target of 80% reduction in carbon emissions in the Climate Change Act [3] and by current government energy planning [11]. Consideration of the energy generation proposals in these scenarios does, however, bring some insight. Thus, under "Resourceful Regions", mass heat pumps installation would be improbable because of the lack of coordination; under "Carbon Creativity", perhaps extremely expensive because of carbon taxation; unlikely and perhaps un-necessary due to the lack of generating capacity under "Sunshine State", but would be reasonably supported under the "Green Growth" scenario by large-scale, low-carbon generation. These are useful, though not subtle, insights, and do not provide a solution to the problem elicited by Fawcett [12] of the domestic heat pump as "following technology", whose credentials as low carbon technology are dependent on large-scale supply of low-carbon electricity, the retrofit of badly insulated housing stock and the change-over to low temperature heat distribution systems. Added to these issues are possibly short-term problems in installation and performance found by the Energy Savings Trust heat pump trials [13,14] and serious, but localised, deficiencies in the electricity distribution network identified in the North Blyth project by Lacey [15], where the connections to dwellings could only support heat pump installations in every other dwelling.

1.3. Previous work

Conventionally, this type of study is performed by means of a disaggregated ('bottom-up') domestic energy model for the UK housing stock, since this provides a mechanism for the input of possible technological changes in heating systems [16]. Estimation of stock-level values involves energy modelling for each of a set of archetypal dwellings, before and after an intervention, and grossing-up the results according to the estimated proportion of these archetypes in the housing stock. There are at least five models of this type for the UK housing stock: BREHOMES [17–19], UK Domestic Carbon Model (UKDCM) [20], DECarb model [21–24], Community Domestic Energy Model (CDEM) [25], Johnston [26,27], employing as their basis widely different numbers of archetypal dwellings, ranging from 2 (Johnston's model) up to 20,000 (UKDCM). BREHOMES modelling is used by BRE, the UK authority for housing energy statistics, to generate the statistics to compile the annual Domestic Energy Fact File [28]. BREHOMES employs a BREDEM-type [29–31] model for dwelling-level modelling, as do the other four, albeit with various enhancements, making BREDEM the de facto standard model for this purpose. Other modelling such as that by Ward [32] has used SAP for a segment of the UK stock to examine the effects of rising temperatures on overheating under conditions of climate change.

Largely, the studies performed using these models examine the effectiveness of various strategies in attaining the carbon emission reduction policy targets current in the UK at the time of their development, viz. 60% or 80% reduction by 2050, and make comparisons with the outcomes without these interventions. Strategies modelled include demand side, i.e. improved insulation and more efficient appliances and heating systems, and supply side, i.e. reductions in the carbon intensity of electricity generation. However, none of the interventions include substantial numbers of heat pump systems, restricting their application to new-build and country properties, despite the fact that heat pumps are the most efficient heating systems currently available as a replacement for gas systems [33,34].

The modelling systems developed by Gadsden et al. [35] and Gupta [36] provide energy and carbon dioxide emission estimates from a survey of a section of the housing stock, representing a parallel path of dwelling energy modelling. These tools employ data reduction techniques to set values for the principal BREDEM parameters based on built form and date of construction, largely the same mechanism as that in the domestic energy models, but based on survey data from actual dwellings.

Kavgic et al. [37], in their review of the five main models in the list above, make the point that data from the English Housing Survey (EHS) is the most suitable basis for such models, in order to mitigate against the issue of reduced reproducibility of results from previous studies because of the non-availability of the detailed input data and assumptions.

2. Methodology

2.1. Development of heat pump and building energy model

To estimate changes in energy consumption and carbon emissions for the English housing stock due to heat pump system take-up, a version of the standard BREDEM-8 building energy model [29] enhanced with a detailed heat pump model [38] was used to process the samples from the English Housing Survey 2007