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An analysis of UK policies for domestic energy reduction using an agent based tool ☆

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HIGHLIGHTS

- Analyse UK energy policy using a novel agent-based domestic stock model.
- Current policies are insufficient to achieve an 80% CO_2 reduction by 2050.
- The addition of a carbon tax on domestic energy use increases the reductions.
- Behavioural change can increase adoption of energy saving technologies.
- The most favourable conditions achieved a reduction of less than 60% from 2008 to 2050.

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ABSTRACT

This paper introduces a new agent-based model, which incorporates the actions of individual homeowners in a long-term domestic stock model, and details how it was applied in energy policy analysis. The results indicate that current policies are likely to fall significantly short of the 80% target and suggest that current subsidy levels need re-examining. In the model, current subsidy levels appear to offer too much support to some technologies, which in turn leads to the suppression of other technologies that have a greater energy saving potential. The model can be used by policy makers to develop further scenarios to find alternative, more effective, sets of policy measures. The model is currently limited to the owner-occupied stock in England, although it can be expanded, subject to the availability of data.

1. Introduction

In 2008, the UK Climate Change Act established an 80% CO_{2e} reduction target to be achieved by 2050, against a 1990 base level (TSO, 2009). Domestic energy use is responsible for 28% of total demand, with approximately 83% of this coming from space heating and hot water (DECC, 2011b). Significant energy efficiency improvements will be required to the housing stock if the overall 80% target is to be achieved – principally fabric improvements (insulation and air tightness), more efficient heating systems and on-site renewable energy generation.

In order to plan to achieve such targets, and to develop appropriate policies, models are used to provide a projection of the likely impact of potential policies, or sets of policies. When focussing on the housing sector, stock models are typically used to analyse the effects of changes. Stock models operate with a set of archetypal dwellings that, when taken together, aim to represent the range of dwellings in the real world stock of interest; then, by tracing the rate of change to the dwelling stock, emission and energy demand reductions can be predicted. UK housing can be split into three broad categories according to tenure. The largest of these, accounting for over two thirds of households, is the owner-occupier sector. In the private rental sector, individuals and companies own dwellings, which they rent out for financial gain. The final sector is the social rented sector where governmental, or quasi-governmental bodies, rent out dwellings to those unable to buy or rent in the private housing market. Due to this ownership structure, improvements to the existing housing stock only occur when their owners decide to carry out such improvements.

Existing stock models do not consider the micro-economic behaviour of the individual household in carrying out their decision making process for installing energy efficient technologies. The Agent Home Owner Model of Energy (AHOME), described in this paper, aims to address this, concentrating on the owner-occupier (homeowner) sector of the market. This paper provides

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a brief overview of existing stock models; discusses the development and validation of AHOME and then presents results of AHOME's analysis of existing government policies under various scenarios. The effect of an additional carbon tax policy is also investigated.

2. Existing domestic energy stock models

Existing models in the domestic housing sector principally adopt a bottom up approach. Such models build up from a set of representative dwellings that can be scaled up to approximate the entire stock. In stock models, the individual unit of analysis is a dwelling, and a model requires a representative set of reference dwellings with different thermal characteristics (e.g. size, detachment, wall type, heating system, etc.). Using an energy assessment tool, the heating and energy demand for each of these reference dwellings can be estimated, based on an assumed usage pattern. Altering the proportions of the reference dwellings can simulate the demolition of existing dwellings and the construction of new ones. Similarly, improving the properties of the building elements can represent retrofit improvements to the existing stock. Together, these two actions represent real world stock changes and can be used to determine the likely effects from such changes. This is a technology rich approach with the potential to provide high levels of detail, including information about the likely adoption rates of different technological solutions under different scenarios. This general approach has been used for a number of models, in both the UK and the rest of the world, e.g. Shorrock and Dunster (1997), Hinnells et al. (2007), Steemers and Yun (2009), and Swan et al. (2011).

In order to understand the operation of these models, it is worth examining one of them in a little more detail. A significant model for UK analysis is UKDCM2 (Hinnells et al., 2007), which has been used for studies such as Boardman's (2007) Home Truths report. The model includes some 20,000 dwelling types to represent the national stock, each of which is subjected to an assessment of its energy demands. By applying changes, and aggregating, national level estimates can be calculated under different scenarios. This is the approach used by Boardman to generate the outputs required for the Home Truths report.

Whilst current, bottom up, stock models apply a technology rich approach to the dwelling stock, they do not do the same with the dwelling occupants. Therefore, they do not simulate occupants' heterogeneous decision making processes when considering energy efficiency improvements. Without including the individual level buying behaviour, the primary role of such models lies with describing what is technically possible. In order to estimate the likely uptake of any technology, there is a need to consider adoption rates based on the expected actions of individual homeowners. This first requires an understanding of the decision making process of the individual householder.

3. Individual dwelling energy modelling

In order to carry out the energy assessment of the individual dwellings in a stock model, UK based models use either the Standard Assessment Procedure (SAP) (BRE, 2011), or its predecessor BRE Domestic Energy Model (BREDEM) (Anderson et al., 1985). SAP 2009 (introduced in 2011) is the version that has been used for the dwelling modelling in this research.

SAP is the statutory method in the UK for the production of Energy Performance Certificates for dwellings, which are required on the construction, sale or let of a property. Table 1 details the main elements that are required for a SAP calculation for an individual dwelling.

Table 1
Data requirements for a RdSAP calculation.

Size	Area: floor, walls, ceiling, openings Room height, exposed wall length
Construction	Age, exposed walls, exposed floors, roofs, doors, windows
Insulation	Exposed walls, exposed floors, roofs, doors, windows
Heating	Fuel type, efficiency, distribution system
Hot water	Fuel type, efficiency
Lighting	No. of incandescent, fluorescent, LED
Renewable technologies	Power of solar hot water and photovoltaic systems, wind turbine dimensions

SAP carries out a steady state estimation of the energy demand per month to provide heating, hot water and lighting. It does this by estimating heat flows into and out of the building: heat losses through walls, roof, floor and windows; solar gains through windows; and incidental heat gains from cooking, lighting, hot water and metabolic heat gains. Physical data is combined with standardised occupancy patterns and heating demands, together with external weather data. For instance, the surveyor assessing a dwelling will determine the construction type of the walls, based on which SAP will assign a standard U-value, U (W/m^2 K) for that wall type. The surveyor will also supply the total wall area, A, and similar figures will be recorded for the other fabric elements: floor, roof, windows, etc. Combining these will produce the total fabric heat loss, as in Eq. (1)

$$\text{Fabric Heat Loss} \left(\frac{W}{K}\right) = \sum_{j=1}^{n} A_j U_j \quad \text{Total fabric heat loss} \tag{1}$$

SAP assumes standardised indoor temperatures, and includes data for average external temperatures on a monthly basis. In essence, the fabric heat loss is multiplied by the indoor/outdoor temperature differential to calculate the power required to maintain the desired internal temperature. The actual SAP calculation also includes ventilation losses and incidental gains from metabolic sources, lighting, etc. This is therefore a steady state model, calculated on a monthly basis. It also estimates hot water demand based on the standardised number of occupants, which is calculated according to floor area, as well as lighting demand.

These net demands are then converted into gross energy demands according to the efficiency of the appliance satisfying that demand. This calculation will also include energy generated by any renewable technologies installed in the home. Outputs are generated in the form of kWh/month for the different demand types – heating, hot water and lighting (as well as a calculation of a theoretical cooling demand, even if there is no cooling system present). For an Energy Performance Certificate, these elements are combined and converted into a SAP rating from 1 to 100 based on cost per square metre. SAP provides an estimate based on standardised occupancy patterns and so may not exactly match the energy demand of any individual household, but aims instead to represent a theoretical average household.

As previously mentioned, with this level of analysis of the individual dwelling, bottom up stock models can provide a technology rich environment that provides a lot of detail on the penetration of many different energy efficiency technologies. However, they do not couple this with a similar level of analysis of the decision makers who decide when and whether to install these technologies. Existing modelling techniques can be enhanced by including details of the homeowner level decision making process, with regard to the installation of energy saving measures. AHOME aims to incorporate a simulation of the individual decision making process into a technology rich stock model, in order to provide a novel and more comprehensive model of this type.