Transforming UK homes: achieving a 60 % cut in carbon emissions by 2050

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Abstract
A number of European Governments, including the UK, have a target for a reduction in CO_2 emissions of 60 % by 2050 compared to 1990 levels. This paper explores the implications for policy towards energy use in homes. A 60 % cut in CO_2 from homes is challenging given increases in the number of homes and in the demands for more heat, hot water, more light, and more appliances. It requires significant action now to put the UK on the right trajectory.

Market Transformation aimed at reduced carbon emissions uses a mixture of information, incentives, and regulation to transform the market for a given product. A Market Transformation approach has been adopted widely across the globe for electrical appliances. Here, the approach is extended to transforming the market for new build and existing homes, low and zero carbon technologies for generation of heat and/or electricity (often referred to as microgeneration) and for lights and appliances.

A computer model has been developed to describe the evolution of the stock of homes to 2050. The model has been validated against historical consumption. Sensitivity analysis has been used to test the importance of a number of assumptions (eg population and climate). The model is used to explore policy scenarios for market transformation and can powerfully inform policy design to reduce CO_2. The model and underlying assumptions has been made publicly available to allow exploration of assumptions and testing of alternative assumptions, and could provide an architecture for other EU countries facing similar policy targets.

Introduction
A model of energy use in homes (the UK Domestic Carbon Model v2) has been developed by the Environmental Change Institute (ECI), and is downloadable from www.eci.ox.ac.uk/research/energy/bmtmodelling.php. The model allows sensitivity and scenario analysis. A similar model of energy use in non-domestic buildings is also being developed by ECI (see a parallel paper by Layberry et al in these proceedings). These two models will form the basis for detailed discussion of trends and policy options with stakeholders.

The work is based on earlier work undertaken in the 40 % House report (Boardman et al). It was undertaken as part of the Building Market Transformation (BMT) project, sponsored by the UK Engineering and Physical research Council (EPSRC) and the UK Carbon Trust. It was used to support the Royal Commission on Environmental Pollution as part of a study on the Urban Environment (RCEP 2007). A separate Research Council funded project, Supergen, will use the projections to explore load and generation profiles in 2050 and the impact on the electrical network. This analysis will be used to refine the potential for energy efficiency and microgeneration, and thus feed back into the scenarios (Supergen website).

There may be much wider application. The UK Government is consulting on a Climate Change Bill, which would make a 60 % cut in carbons emissions by 2050 legally binding. The bill would introduce 5 yearly targets, and monitoring and reporting procedures (DEFRA 2007). The bill is open to consultation to 12 June 2007 and because it is a Government bill, it is expected to go through Parliament in the Autumn of 2007, becoming law in 2008. The two models reported here, and separately by Laberry, together account for almost half of UK CO_2 emissions.

About the model

A model of the UK housing stock has been constructed using data from the various housing condition surveys (English, Scottish and Northern Irish). This stock model contains a number of categories of buildings, each category representing a number of real world dwellings such that the sum of the dwellings in the stock model equals the number of dwellings in the country in 1996. In each building category is information about the building fabric (windows, walls, lofts, storey heights, air change rates etc.) and internal demanded temperatures. The majority of the information was taken from the English House Condition Survey (EHCS) 1996 which contains structural information for almost 30,000 representative dwellings.

Using the mean UK external temperature (1970-2000), monthly energy balance equations were constructed which calculated the mean energy flows and therefore energy demands from the heating system necessary to keep a given mean internal temperature, based on BREDEM-8 (Anderson et al 2002). These energy flows take account of gains from cooking, metabolism, solar and waste heat from hot water and lights and appliances. The heat demand over the stock is satisfied by a specific breakdown of heating systems that includes gas boilers, electric heating, solar thermal and solid fuels, and in future years such technologies as CHP (Stirling cycle, fuel cell, district heating), heat pumps and biomass heating.

Electricity demands in future years can be offset by on-site generation (CHP and solar PV). The calculations result in monthly fuel demands (gas, electricity, coal/oil, biomass) from the UK housing stock. These calculations are repeated for all months over one year. At the end of each year, the housing stock is updated (new build, demolition and retrofits) and the process is repeated for each month of the next year. Within each year are defined the heating system breakdown, demand for hot water, demand for lights and appliances, internal temperatures etc. The result, when aggregated, is the end use demand (space heating, cooking, lights and appliances, hot water), the fuel demand (gas, electricity, coal/oil, and biomass) and the carbon footprint (using historical and predicted carbon emissions factors) of the UK housing stock on a yearly basis from 1996 to 2050.

Scenarios have been constructed of alternative build and demolition rates, fabric improvements, microgeneration installation rates and efficiencies, improved efficiency in lights and appliances, as well as changes in human behaviour. The scenarios explore the potential for carbon reduction in 2050 in comparison to 1996 (or 2005) using external monthly mean temperatures given by the climate in the UK 1970-2000. This takes out the effect of weather events, either historical or predicted (comparison between an uncharacteristic 1996 and an uncharacteristic 2050 will affect the results considerably). Climate change can be modelled by applying a shift in external monthly temperatures.

In order to aid transparency of the modeling and results, a package of materials is downloadable from the ECI website, including

- A spreadsheet of results from three scenarios.
- The UK Housing Stock 2005 to 2050: a report on assumptions used in Scenarios and Sensitivity Analysis in UKDCM2. The basis for all assumptions in all three scenarios and the sensitivity analysis 2005-2050. Includes discussion of the socio-technical interactions and economic implications, and discussion of the policy framework that might bring about these scenarios.
- The UKDCM2 model, together with a Manual on how to install and run the model. In order to run the model, the following software is needed: IDL (see IDL website), Exceed and Putty (see Manual).

Results

The outputs of the modelling include:

- **A comparison of modelled consumption to actual energy supplied** over 30 quarters of data from the Department of Trade and Industry quarterly publication *Energy Trends* (available on the DTI website). The model has been validated in that seasonal variation,and trends over time can be closely replicated (Figure 1).
- **Error analysis.** Estimates of the level of loft insulation installed or airtightness of buildings in the stock are not 100 % accurate. It is necessary to understand how sensitive the model is to inaccuracies in input data.
- **Sensitivity testing** on future assumptions like population and number of households, and internal and external temperatures. The base assumptions for these factors are described in the report, The UK Housing Stock 2005 to 2050, downloadable from the ECI website.
- **Three policy scenarios** (Figure 2). The scenarios take into account an expected 33 % increase in the number of UK homes by 2050 (due mainly to falling household size) as well as increasing internal temperatures, increasing demands for hot water and appliance ownership. The scenarios explore new build, refurbishment of existing homes, possible fabric improvements, low and zero carbon technologies and improvements to lights and appliances through to 2050. The underlying trajectory of technical change and thus emissions is the main focus. The three scenarios are:
- **Scenario A, Incremental Change**. Based around current policies and technologies. Increases in service, as well as new appliances and services are likely to continue to wipe out (as has happened for the last three decades) improvements in efficiency for the foreseeable future, resulting in no significant reduction in CO_2 from the stock .
- **Scenario B, a 40 % Scenario**. Because of an expected 33 % increase in the number of dwellings by 2050, as well as more heat, more hot water, more appliances, a reduction to 40 % of current emissions requires that existing dwellings move from average E to average Aon the new Energy Rating scheme for dwellings (similar to the energy label for appliances, upwards of 80 % ownership of Low or Zero Car-

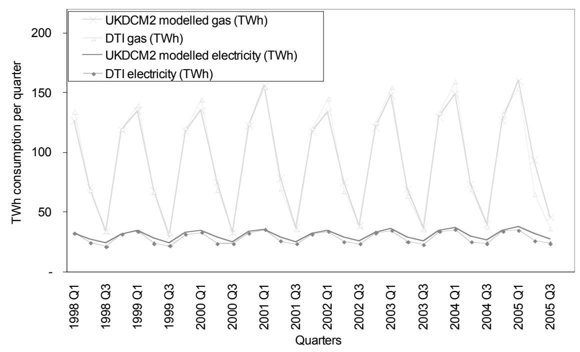

Figure 1 Validation of modelled data against actual energy supplied.

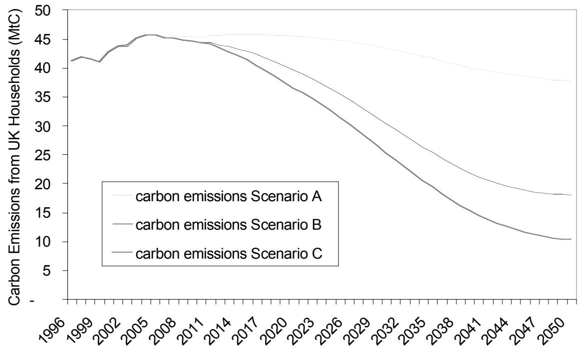

Figure 2 Scenarios for carbon emissions out to 2050

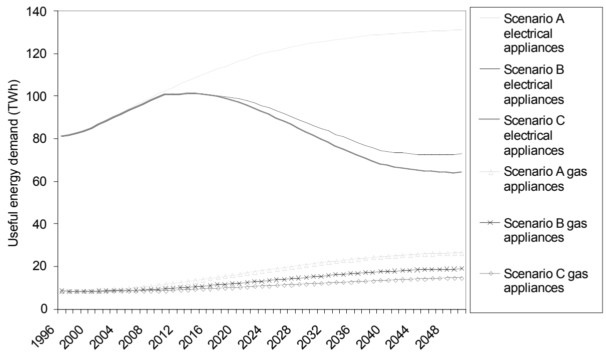

Figure 3 Scenarios for energy used in lights and appliances out to 2050

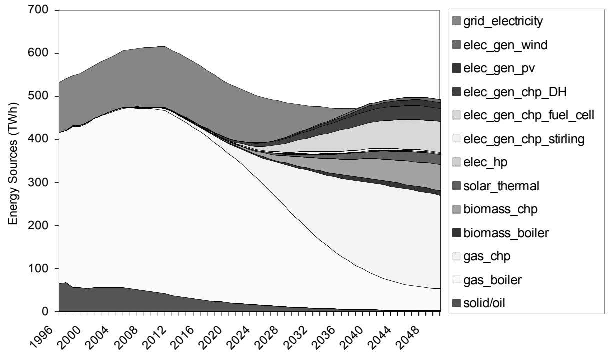

Figure 4 Energy supplied from a range of sources out to 2050 (Scenario C)

bon technologies for heat and or electricity, and a halving of projected lights and appliances consumption.

- **Scenario C, Extreme Change**. A 50 % reduction against current emissions by 2030 is shown to be feasible with a 75 % reduction against current emissions by 2050.

Findings

The model provides a valuable tool in enabling discussion with stakeholders on needs and priorities in achieving significant carbon reductions. Key conclusions include:

For **new build**, the need is to establish now a target of zero carbon new build by 2020 at the latest, with intermediate steps in 2015 and 2010. The EU Energy Efficiency Action Plan calls for zero carbon homes by 2016 (EU Commission 2006).

For **refurbishment of existing homes**, point of sale and the launch of the Home Energy Rating (as a result of the EU Energy Performance of Buildings Directive) provide a major opportunity. Increased label visibility, an obligation upon mortgage providers to lend for refurbishment and a requirement on householders to achieve certain improvements could all transform the market.

For **lights and appliances** (Figure 3) the major efficiency improvements are in refrigeration, consumer electronics and lighting. Minimum Efficiency Standards under the *EU Energy Using Products Directive* must play a key role. At present the EU only has 3 product standards, whereas there are currently over 200 mandatory standards in place globally. The EU Energy Efficiency Action Plan is promising in this regard. Fuel switching is important in Scenario C, but is not yet a major policy issue. The growth of new products (like hot tubs and patio heaters) is significant in Scenario A, and constrained in Scenario C.

For **microgeneration** there are three basic opportunities:

- *Combustion based opportunities* – generate heat and may also generate electricity (as CHP). Community heating is predominantly a technology for dense urban communities. Micro CHP is a suburban technology
- *Rooftop opportunities* – PV, solar thermal, micro-wind
- *Rural opportunities* – biomass or heat pumps

The three scenarios A, B and C explore combined uptakes of microgeneration of 40 %, 80 % and 120 % by 2050 respectively, meaning that some homes may have more than one device (eg solar thermal and PV, possibly in a single integrated device). Homes may generate (on a year round basis) as much electricity as they consume; demand for gas may decline and be used substantially in CHP rather than in heat-only applications (Figure 4). The bifurcation needed in the energy market is so profound that change may be organisational, with a key role for Energy Services Companies. New build housing developers are likely to want to retain their current business model, of design, build, move off site, but will still need to incorporate microgeneration, due to planning requirements. In 2006 the UK Chancellor of the Exchequer announced that homes which were zero carbon would be zero rated for stamp duty (normally 2-5 % of the purchase cost of a home) (HMT 2006) to achieve zero carbon in order to gain stamp duty exemption. However,

Figure 5 Distribution of gas use by house type

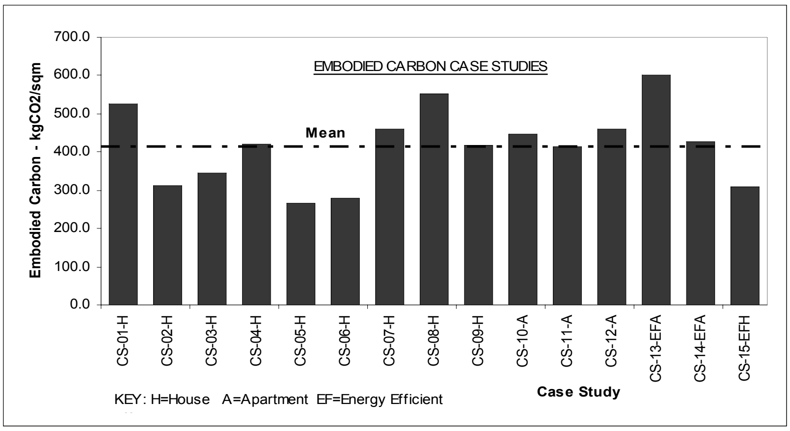

Figure 6 Embodied Carbon from a range of case study dwellings

microgeneration needs management in order to ensure it continues to deliver. One option is for developers to subcontract out all energy issues to an ESCo (Energy Services Companies) to design, build, finance operate and maintain microgeneration.

Behaviour is hugely important. The model describes consumption and changes to the *average* dwelling (taking some 431 dwelling types). However, consumption varies hugely based on behaviour (occupancy, temperatures, hours of heating, understanding of the heating system etc) and consumption is only loosely related to dwelling type. Figure 5 shows the distribution in gas use for the main dwelling types. For the same dwelling type, consumption can vary by an order of magnitude (both figures based on analysis of the English House Condition Survey datasets for 1996, but only for homes with both electricity and gas, and only for homes for which there is two years worth of metered energy data) (EHCS 1996). Given behaviour is important, then targeting technical intervention at high consuming households could mean making the same savings with fewer installations. Changing behaviour could be a key element of policy. For example, a recent initiative to address behavioural change is the UK Demand Reduction Pilot, which begins in the spring of 2007 and will test various forms of feedback to householders and SMEs over two years to assess how much they have to offer in helping consumers to reduce demand.

Work on **embodied carbon** is well advanced. A database of materials has been collected by Bath (Hammond and Jones 2006). A key conclusion is that there is a factor two variation in the embodied carbon of recent new build dwellings in any case, with houses being lower in embodied carbon per m² than flats (Figure 6). Early indications are that low energy dwellings need not be any more intensive in embodied carbon terms, though there is uncertainty at present in this conclusion, with the result sensitive to thermal mass, the amount of recycling (especially of higher physical and thermal mass materials), and choice of materials eg flooring.

Conclusions

The future is unknowable, but can be explored through scenario analysis and sensitivity analysis. This model provides a framework for detailed, bottom-up exploration of residential energy use, and what would drive emissions upwards (eg increased demand for homes, or for energy services), what may reduce emissions (improved efficiency or lower carbon sources of heat and electricity either from the network or from Low and Zero carbon technologies), as well as exogenous variables (like effects of population growth or climate). It is already in use by others and can be downloaded from the web for further, more detailed analysis. It may also provide the framework for analysis of measures to implement legally binding targets and for monitoring of such targets. A similar framework with a different dataset could be applied to another jurisdiction, eg a region of the UK, or another EU country. The work therefore has wide applicability.

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