Policy Studies Institute

Climate change and fuel poverty

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Executive Summary

The research examined the possible effects of rapid climate change on fuel poverty (needing to spend more than 10% of income to maintain a satisfactory level of warmth and other energy services in the home). One particular concern was the prospect that there might be a shutting off of the Gulf Stream, which warms Britain and the rest of north-western Europe. Computer simulations of the climate indicate that shutting down the Gulf Stream would cool England by about 3°C. Climate is not the only variable that will affect future levels of fuel poverty. The other main ones are what will happen to the energy efficiency of the building stock, to incomes and to energy prices. The aim of the project was to examine what might happen to each of these four dimensions and construct three scenarios in each dimension (most likely, high and low) to capture the range of variation in possible outcomes. A total of 81 (3x3x3x3) scenarios were modelled and analysed. Since any changes in the climate system take decades to play out, but it is extremely difficult to predict social, economic and technological changes even 25 years in the future, it was decided to set an objective for this research of looking forward to 2030.

The Government has a target to abolish fuel poverty 'as far as reasonably practical' by the end of 2016. It has also set the target of reducing UK carbon dioxide emissions by 60% from 1990 levels by 2050, implying a 40% reduction by 2030. The outcomes of the scenarios modelled were compared against those targets.

It was found that even with increasing temperatures, the sort of energy efficiency improvements likely by 2030 would be insufficient to reduce carbon dioxide emissions from households by 40% from 1990 levels. However, if all technically possible energy efficiency measures were carried out by 2030, the target would be met with increasing temperatures and would almost be met even if the Gulf Stream shut down. That would be a challenge for policy, as it would involve insulating solid walls, which is difficult, expensive and controversial.

It was found that fuel poverty diminishes from recent levels in most scenarios, although it rises in some, but that in order for fuel poverty to be reduced to extremely low levels, what is required is a redistribution of wealth to boost the incomes of the poorest by much more than could be expected from economic growth alone. A large improvement in energy efficiency is also required. If fuel poverty is to be eliminated, extensive solid wall insulation is not necessarily required because micro-CHP can do almost as much as solid wall insulation to reduce bills, although it does not have nearly as much effect on reducing carbon emissions, so the carbon reduction target is not met.

Introduction

One issue that global warming might be expected to actually help with is fuel poverty. However, it will very probably weaken, and may possibly stop, the thermohaline circulation (THC). One part of the THC is the Gulf Stream, which becomes the North Atlantic Drift that warms Britain and the rest of north-western Europe. Climate change could possibly make Britain become colder, not warmer over the next few decades (Hulme 2003). If that were to be the case, it would increase fuel poverty compared to what it would be otherwise. The ESRC commissioned this research to examine the possible impacts of climate change involving both warming and cooling on fuel poverty.

Fuel poverty is defined as a household needing to spend more than 10% of its income on energy in order to maintain a 'satisfactory' level of warmth (DTI/DEFRA 2001). This is set at 21°C in the living room and 18°C in other rooms. The effect of any change in climate on the level of fuel poverty will depend not simply on external temperatures, but on the level of insulation of the home, the heating technology, the price of energy, the amount of economic growth experienced and the effect of changes in levels of inequality on incomes among vulnerable groups. The approach taken to the research was to model the effects of these factors.

Since even rapid climate change would take a few decades to change temperatures by a few degrees, it was necessary to look at how all those different factors might develop over the next decades. The scenarios examined the effects by 2030 because effects that are rapid in terms of the climate system will necessarily take decades to play out. We did not look more than 30 years into the future because the social and technological changes that can be expected make prediction extremely difficult and uncertain.

What will happen to fuel poverty in future will depend not only on external temperatures, but on the level of insulation of the home, the heating technology, the price of energy, the amount of economic growth experienced and the effect of changes in levels of inequality on incomes among vulnerable groups. A matrix of scenarios were developed varying according to different outcomes not only for external temperatures, but the other dimensions identified in order to construct a series of models describing the range of potential effects of climate change on fuel poverty. For each of the four dimensions, three scenarios were developed and they were combined to produce a grid of 81 (3x3x3x3) different scenarios. In each case, the central scenario represented what was considered most likely and the other two cases represented the extreme cases. Since a shutdown of the THC by 2030 is very unlikely, the other extreme cases were also unlikely. The aim of the project was not to predict the future, but to show the range of the possibility space within which the future might be found.

Possible climate change impacts

Climate impacts from greenhouse gas emissions are calculated on supercomputers using global circulation models (GCMs). Most current GCMs predict that following a 'business as usual' path of increasing emissions the Earth as a whole will most likely warm by one to several degrees Celsius over the course of the century (IPCC 2001).

There are two categories of variation: uncertainty about future levels of emissions and uncertainty about the climatic impact of emissions. The uncertainties about future emission levels boil down to uncertainties about the level of economic growth, the pattern of energy intensity and the fuel mix used to provide energy. The uncertainties about the climatic impact are much more complex. Essentially, there are a number of feedback mechanisms that are not well understood. The effect of clouds on warming is not precisely understood and changes in cloud cover may either reduce or amplify warming. Conversely, there are sources of greenhouse gases that could strongly amplify warming beyond the levels currently predicted in most GCMs. Unlike other GCMs, the Hadley Centre's models take account of the interaction between the climate and the carbon cycle. Forests and soils are both currently absorbing very large amounts of carbon, but the Hadley Centre predicts that will fall off very rapidly, making climate change develop more quickly and with more intensity than in simpler models (Cox et al. 2000).

A different uncertainty is about the sensitivity of the THC to global warming. It is thought that warming of a few degrees will most likely only reduce the strength of the THC by around 15-25% (Hulme 2003). No climate models predict collapse of the THC by 2030 and in those that do predict collapse later the warming by that point usually more than offsets the cooling, so that temperatures are lower, but remain above present-day levels. However, it is possible that the THC is much more sensitive to temperature variations and could be greatly diminished or even switched off entirely once an unknown threshold is passed. After the completion of this research it has been reported that collapse of the THC is more likely than previously thought (Schlesenger et al. 2005). The THC warms the air over the North Atlantic, the British Isles and Scandinavia by several degrees C. A simulation of the collapse of the THC after the threshold is crossed found a rapid cooling by 3°C in a few decades and a further gradual cooling by another 3°C over several centuries (Rahmstorf and Ganopolski 1999). A more detailed simulation by the UK Meteorological Office predicted a rapid cooling by 3°C in central England temperatures over a few years after the THC was instantaneously switched off (Vellinga and Wood 2002). In this simulation, the cooling was greatest in the first decade due to reinforcement by sea ice effects, before lessening slightly.

The literature indicates that if the THC switched off there would be greater cooling in winter than in summer (Rahmstorf 2003). That is important, because it would increase the impact on energy consumption and fuel poverty. However, Hulme (personal communication) and Wood (personal communication) state that the seasonal difference is small.

It should be noted that a 3°C cooling is in a climate with constant levels of greenhouse gases in the atmosphere. The United Kingdom Climate Impacts Programme (UK CIP) has examined a range of scenarios for the likely effects of climate change on the UK over the course of the century. For the purposes of this project, an estimate of around 1°C was taken to be the approximate level of likely warming.

That means that in the unlikely event that the THC collapses by 2030, the degree of *net* cooling that could be expected would be around 2°C. The cooling would be slightly greater in the winter than the summer. To give some sense of what such a cooling would mean, London temperatures would become like temperatures in Bergen are in the present day.

Since collapse of the THC is unlikely, it is sensible to compare its effects with what is likely to happen (warming of around 1°C) and with a similarly unlikely change in the other direction. Mike Hulme advised that since collapse of the THC so soon is not predicted by any climate model, an amount of warming which is beyond the level predicted by any model should be used to represent a similarly unlikely case. He suggested a warming of 4°C on average, although more in the summer than the winter. This is equivalent to the level of warming UKCIP predicts by the 2080s, leading to temperatures similar to those found in southern France in the present day.

So the project examined the effect on England of three scenarios for 2030: gradual warming by around 1°C, rapid warming by around 4°C, and collapse of the THC leading to *net* cooling of England by around 2°C.

For the moderate warming scenario, the 2030 Low Warming projection by the UK Climate Impacts Programme (UK CIP) was used in the modelling. It predicts an average warming of 0.98°C, seasonally distributed as follows:

Spring +0.83°C
Summer +1.18°C
Autumn +1.13°C
Winter +0.77°C

For the high warming scenario, a 4°C rise by 2030 is well above what UK CIP predicts. It is close to the 2080 High Warming projection by UK CIP, which was used in the modelling, with an average warming of 3.80°C, seasonally distributed as follows:

Spring +3.23°C
Summer +4.56°C
Autumn +4.40°C
Winter +3.00°C

For the cooling scenario, Vellinga and Wood (2002) could not provide a regional temperature grid of the kind provided by UK CIP. Their model was much less geographically detailed. Wood (personal communication) states that there is only slightly more cooling in winter than in summer. Reductions in temperature ranging sinusoidally from 2.5°C in July to 3.5°C in January were overlaid on the 2020 Low Warming projection. The net cooling was 2.02°C, distributed seasonally as follows:

Spring –2.02°C
Summer –1.41°C
Autumn –2.02°C
Winter –2.64°C

Possible energy efficiency improvements

The Energy White Paper (DTI 2003a) committed the government to put itself on a path to reduce the UK's carbon dioxide emissions by 60% from 1990 levels by 2050 (equivalent to 64MtC in 2050). It set an interim target of 105-115MtC in 2020 (around 30% below 1990 levels). Following a linear path to the 2050 target of 10% each decade gives around 95MtC in 2030 (40% below 1990 levels). The Energy White Paper also sets the target that 'as far as reasonably practical' no household should be in fuel poverty by 2016. It is presumably intended that fuel poverty should not then increase after 2016.

The official definition of a 'satisfactory' heating regime is 21°C in the living room, 18°C in the other rooms - that is for 16 hours if people are in all day, 9 hours if everyone goes out to work or school, and only half the rooms if the home is considered underoccupied (DETR 2000). That is considered an ideal and the 'minimum' heating regime (18°C and 16°C respectively) is regarded as a more appropriate target. The energy efficiency of homes in rated according to the Standard Assessment Procedure (SAP), a scale running from zero (extremely inefficient) to 120 (extremely efficient). The average English home in 1996 had a SAP of around 46, although it had risen to 51 by 2001. The 1996 English House Condition Survey found that only at SAP 40 does average energy consumption of households meet the minimum heating regime and only at SAP 60 does average energy consumption of households meet the satisfactory heating regime. According to the official definition of satisfactory heating, over 80% of homes were insufficiently heated in 1996 and nearly half of homes were not even heated to the minimum standard (DETR 2000).

The modelling undertaken for this project examined three different scenarios for household energy efficiency and calculated the effect on energy use using the model of the building stock developed and operated by the Environmental Change Institute at Oxford University. The three scenarios were one with maximum efficiency, a most likely scenario and one with minimum efficiency.

The ECI model uses data from the national House Condition Surveys. This project used the part of the model that relates to England and relies on the 1996 English House Condition Survey. The ECI model uses the 12,131 homes in the physical sample to represent the entire English housing stock, with each home assigned a weighting factor to signify the number of dwellings it represents. The model calculates the expected energy consumption of the dwelling to achieve a particular level of heating and use of lighting and appliances set as desired (Sinden and Lane 2004). The model used is being developed for the Tyndall Centre's 40% House project, which is examining the prospects for reducing the carbon emissions from households to 40% of their 1990 levels by 2050. The characteristics of the homes existing in 1996 can be adjusted over time, adding insulation measures and changing the heating system. The model also constructs new homes to meet increases in number of households and demolishes old ones. The physical characteristics of the new houses are based on those of existing houses built between 1980 and 1996, except that the insulation standards and heating systems are set to meet the building regulations expected in the year that they are built.

In the 40% House project, scenarios based on the four Foresight scenarios have been developed to examine the changes that might occur by 2050. Those scenarios were not used here. Instead, scenarios were developed independently, except for the growth in household numbers, as revising that aspect of the existing model would have involved substantial additional work for ECI. For that aspect, the reference scenario derived from official projections and two of the variant scenarios were used. The ECI model only considers the physical aspects of the housing stock, not the economic aspects, and only outputs the energy and carbon consumption expected. It has no projection for future incomes or their distribution and no projections for future energy prices. It also does not (yet) consider the changes in the carbon content of electricity in future. These aspects of the scenarios are not just independently developed, but new and external to the ECI model.

An important aspect in which this use of the model differs from the 40% House project is that there household temperatures are assumed to rise over time according to the trend expected in that scenario, whereas what was calculated in this project was the energy consumption, carbon emissions and costs based on an assumption of the standard heating regime (21°C in the living room and 18°C in other rooms). When looking at the results, it is important to remember that the results are not calculations about actual energy use, carbon emissions and costs, but those that would be the case if all homes followed the standard heating regime.

It was decided not to assume the use of air conditioning to ameliorate high temperatures because could instead be criticised for obscuring the main aspect of the Government's targets for fuel poverty - meeting the target in terms of standards of warmth – and making it more difficult to achieve. It is unlikely that there will be a large uptake of air conditioning or other cooling technology in private homes by 2030, except in the rapid warming scenarios. In those scenarios, there could be a case for regarding cooling as a necessity, but to incorporate such an assumption into the calculations could have been accused of moving the goalposts in order to make achievement of the fuel poverty and carbon emissions reduction targets more difficult and so it was not done.

After canvassing the advice of experts, it was thought most likely that improvements in future would be rather more rapid than those in the past because of the target for the elimination of fuel poverty and because of concern to reduce carbon emissions. However, it was possible that there would be a loss of interest in these issues in future years so that improvements would be closer to their historical level. On the optimistic side, combined with political commitment to promote insulation, more efficient heating systems and better building regulations, could lead to very significant improvements in efficiency and reductions in carbon emissions. In all the scenarios, it is assumed that central heating becomes universal (the standard heating regime cannot sensibly be met without it), whether it is based on gas, electricity or wood – other fuels such as coal and oil are no longer used for domestic heating in the scenarios for 2030.

The introduction of new technologies was considered in some of the scenarios. Domestic CHP (dCHP) and heat pumps are new technologies that are not yet in widespread use in Britain, although heat pumps are used in other countries. Both have higher capital costs than existing heating technologies, but are much more efficient.

dCHP is only as efficient at producing heat as a good conventional boiler, but it produces electricity which replaces electricity from the grid, overall reducing carbon dioxide and saving the household money. Unfortunately, dCHP technology is not likely to be suitable for use in every gas-heated home even by 2030. The technology which exists and is being commercialised is based on Stirling engines. They cannot efficiently be scaled below a certain size. A Stirling engine is only efficient in a home with a minimum annual thermal demand (space heating and hot water) of at least 12,000 kWh per annum. In 1996, only 11% of gas-heated homes had a heating demand below this level (Crozier-Cole and Jones 2002), but with greater insulation by 2030 the number of homes suitable for dCHP falls. Fuel cell technology would enable dCHP to work in smaller, better insulated homes, but it is unlikely to be commercialised before 2020-25 (Harrison 2002), too late to play any role in the scenarios here.

Micro-CHP generates significantly less electricity than the total number of kilowatt hours that the homes uses in the year, but there are periods of time when the micro-CHP unit is generating more electricity than is being consumed in the home. That surplus electricity is sold to the network. The simplest assumption is that it is sold at the same price as retail electricity, particularly because micro-CHP tends generate most at periods of high general electricity demand (because peak heating times are also times of peak use of electrical appliances).

Jeremy Harrison of Powergen CHP (personal communication) recently informed us that in trials of micro-CHP, utilisation of the electricity generated has been about 60% to 85%. The value of electricity generated depends on when it is produced and what the marginal cost of generation is at that time. Their studies have found that the electricity is worth 2.5p/kWh to 3.5p/kWh. That is 3.25p/kWh to 4.25p/kWh less than the price of standard electricity. However, because the surplus electricity tends to be generated at peak times (usually when boilers come on in the morning and sometimes in the evening), utilities can also offer slightly lower prices for electricity taken from the grid because they will not need to provide as much electricity at expensive peak times. It was therefore assumed in the calculations that follow that 30% of the electricity generated by micro-CHP was surplus and sold to the network at 3.75p/kWh less than the prevailing price of standard rate electricity to the consumer. The effect of this change compared to an assumption of net metering was fairly marginal.

The ECI model does not install dCHP with regard to the thermal demand, but simply a set proportion of the gas-heated homes in each category of housing. The ECI model is designed to give results for 2050 when fuel cell dCHP is likely to have been available for some time. The problem is that although in 1996 only 9% of gas-heated homes had a heat demand of less than the 12,000 kWh per annum taken to be the minimum for an efficient Stirling engine, in the maximum efficiency scenario about 50% of homes have a thermal demand below this level. In order to more accurately assess the impact of dCHP and not overstate it, PSI therefore made further calculations to adjust the results from the output of the ECI model in order to allocate dCHP only to gas-heated homes that could efficiently use it and instead allocate condensing boilers to homes that could not.

The scenario for maximum efficiency was set based on the assumption that government would undertake measures to ensure that the most efficient heating technologies were adopted universally (dCHP for homes heated with gas and a thermal demand above 12,000 kWh, condensing boilers for homes heated with gas and a thermal demand below 12,000 kWh, heat pumps for houses with electric heating and wood-burning stoves for houses that presently use other fuels, mostly coal); insulation was increased to the maximum level in all homes; for new homes standards were progressively increased and solar power (both photovoltaic for electricity and thermal for hot water) would be mandatory for new homes from 2010. The scenario does not assume completely new technologies, but that the best performance from technologies now available is universal by 2030. After some consideration, it was decided to maintain the demolition rate at present levels. An allowance was made for an expected increase in electricity consumption by consumer electronics despite efficiency improvements as the amount of equipment increases very substantially. Conversely, it was assumed in this scenario that incandescent lighting would be entirely replaced by more efficient technologies such as compact fluorescents (CFL) and light-emitting diodes (LED).

There are two main kinds of heat pumps: ground source heat pumps and air source heat pumps. The former are more efficient, but would not be practical in many homes presently with electric heating as a garden is needed to act as a ground source. The use of air source heat pumps was modelled, even though in reality some homes would have the better ground source heat pumps. An efficient air source heat pump currently costs a few thousand pounds, but they are cheaper in other countries and the price is expected to fall substantially. An air source heat pump would reduce electricity demand for heating by over 70% compared to conventional electric heating.

Rates of loft insulation have remained stuck at around 90% for the last twenty years, although the thickness of the insulation in those homes that have it has gradually increased over time. In this scenario, it is assumed that all loft insulation is upgraded to the equivalent of 300mm of standard loft insulation (the level set by Building Regulations from 2005). Floor joists are usually only between 100mm and 150mm deep, but there are a number of options to increase the effective insulation above that level. Extra insulation can simply be laid over the joists, which is the cheapest and simplest option, but one which makes it difficult to safely walk about the loft and means that the loft cannot readily be used for storage because the weight of items on top of the insulation crushes it and prevents it from being effective. Another option which is slightly more expensive is to hang additional insulation in netting at the level of the rafters. The third option is to use more expensive but more efficient insulation that is twice as effective so that 150mm of this insulation is equivalent to 300mm of standard insulation – the cost of the material is about 50% greater than 300mm of standard insulation. The fourth option and most expensive option is to use solid decking insulation that can be fitted over the joists and with 100mm of mineral wool insulation between the joists achieves a u-value equivalent to 300mm of standard loft insulation.

Cavity wall insulation is not suitable for all homes with cavity walls. It had been estimated that because of problems with rain penetration only 80% of cavities could be filled (Shorrock et al. 2002), but more recently there has been a change of opinion and it is now thought that about 95% of cavities can be filled (Shorrock, personal communication). In this scenario, it is assumed that the remaining 5% will instead be insulated with more expensive and inconvenient insulation that is normally applied to solid walls. Cavity wall insulation brings the u-value of a cavity wall down from about 1.6 to 0.35 and internal or external wall insulation can achieve about the same.

The most difficult aspect of the scenario to bring about would be ensuring that all solid-wall homes have wall insulation. Internal wall insulation (dry lining) of 6cm would typically reduce the u-value of a solid wall from 2.1 to 0.45. Since solid-wall dwellings are the most inefficient part of the building stock, achieving really substantial energy and carbon savings requires insulating their walls. The scenario assumes that such insulation would be heavily subsidised (or even free) to encourage households to add it when they would decorate the walls in a room. Such insulation typically costs £1000 per home. External wall insulation is more expensive, although slightly more effective, and there would probably be objections on aesthetic grounds if it was applied to some houses.

The assumption of 100% take-up of these measures is somewhat utopian, but very high rates of uptake could be achieved if there was sufficient political will to improve efficiency standards for products and to actively ensure that heavily subsidised insulation measures were taken up. It is unlikely that solid wall insulation could be done on such a scale, but unless walls are insulated the heating demand from these homes will always be high. This scenario is designed to show the potential for improvements in energy efficiency by 2030.

In this scenario, the issue of cost-effectiveness to the consumer has not been the criterion, but rather reducing energy consumption and carbon emissions as far as possible. Good loft insulation and cavity wall insulation are cost effective at present prices and with present energy prices at normal discount rates. Internal and external solid wall insulation have long payback times and are not currently considered cost-effective in most cases. Micro CHP will be cost effective when it reaches the market. In Britain at present heat pumps are only cost-effective in some electrically-heated homes, because the capital cost is high – a few thousand pounds. However, heat pumps, particularly air-source heat pumps, are cheaper in other countries where there is a larger market because they can also be used for cooling. The running costs of a heat pump are similar to gas heating and the carbon dioxide emissions are significantly lower. Solar thermal is already cost-effective to install on a new roof, but solar photovoltaic is not.

On the next page is a table of the main parameters of the maximum efficiency scenario:

Table 1: Maximum Efficiency Scenario –Key Model Parameters

Parameters	Scenario 1	Scenario 1 Notes
Demolition	25,000pa across England in proportion to number of dwellings in each region	
Solid Walls	100% insulation to u=0.45 by 2030	
Cavity Walls	100% insulation to u=0.35 by 2030	
Solar PV	Uptake equals new build rate from 2010	
Solar Thermal	Uptake equals new build rate from 2010	
Space Heating	dCHP in all gas homes >12,000kWhT; condensing boilers in all gas homes <12,000kWhT HP replacing all electricity	dCHP 77% heat 15% electricity; condensing boilers 92% efficient HP 350% efficiency
Doors	No change	
Double Glazing	100% installation to u=2.0 by 2030, linear increase	
Floors	No change	
Air Changes	Gradual improvement to 2030	
Loft Insulation	100% coverage of available to 300mm	
Electricity Demand	Lighting	20% of current
	Cooking	100% of current
	Consumer Electronics	200% of current
	White Goods	100% of current
Internal Temperatures	21C in living room and 18C in other rooms	

The medium efficiency or 'most likely' scenario was the most difficult to construct. For technologies already in widespread use, it was decided to start from projecting forward to 2030 the curves of uptake rates shown by Shorrock et al. (2002) until saturation was reached, but making allowance for improvements in standards and additional uptake due to the planned increase in energy efficiency programmes in order to meet the fuel poverty target for 2016 and an expectation that they will continue because of concern about climate change.

Following the curve suggests that by 2030 95% of windows will be double-glazed and 100% will be draught-proofed. If ownership of cavity wall insulation follows the long-term curve since 1970 then by 2030 it will have reached 70%, although only 55% if it follows the rate of the last decade. However, the Government has increased the funding for Warm Front and increased the size of the Energy Efficiency Commitment for 2005 to 2011. The two programmes are planning to insulate 4.4-5.7 million of the 12 million cavities (about four million of which are already filled) over the next six years. Since it is now believed that 95% of cavities can be filled, it is reasonable to suppose that nearly all of those are likely to filled by 2030 unless there is a complete collapse in political will after 2011. To allow for some being missed, the rate of cavity wall insulation is set at 90% in this scenario.

Ownership of loft insulation has remained stuck a little above 90% since the mid 1980s and 40% have less than 100mm of insulation, but it is unlikely that this situation will be allowed to continue for the next 25 years. Loft insulation officially only has an effective life of 30 years and the insulation installed in the 1970s is now due for replacement.

In the medium efficiency scenario it is assumed that after 2011 loft insulation will be subject to a big renewal effort as the installation of loft insulation was the first time in the period 1974-84 when government grants were available to all householders and as cavity wall insulation will be in 2005-11. Building regulations from 2005 will require the installation of 300mm of loft insulation in new buildings. Warm Front and the Energy Efficiency Commitment install loft insulation at the thickness set by building regulations unless the householder asks for less. As discussed above, there are practical difficulties with installing more loft insulation than the thickness of the joists, but there are ways to install the equivalent of 300mm of standard loft insulation that do not interfere with the loft being used for storage. It is assumed that those technologies will be used in order to bring lofts up to the standard set by building regulations. The additional cost should be justified because the old loft insulation will be losing its effectiveness and will need to be replaced anyway. It is assumed that in 2030 90% of lofts will be insulated (more will have insulation down, but it will have become ineffective) and that those lofts with less than 200mm (the standard in 2000) will have been replaced with the equivalent of 300mm.

Projecting forward the current rate of solid wall insulation, 10% could be expected by 2030. Because external wall insulation is expensive and not very attractive, while internal wall insulation is inconvenient, it is assumed that there will not be a significant increase in the rate of uptake.

It was difficult to decide what would be the likely uptake of new technologies - dCHP, heat pumps, solar PV and solar thermal – for which there is no historical experience to draw on. A lot will depend on what happens to the costs of these technologies over the next 25 years. However, an analogy can be drawn with the experience with condensing boilers over the last 20 years. The capital cost of condensing boilers has not been very much greater than that of conventional boilers, but they account for only about 10% of the market because boilers are usually a distress purchase and people tend to buy cheaper ones or combi boilers to save space, without much regard to future energy costs. New efficiency standards for boilers mean that from 2005 nearly all boilers will be condensing, but dCHP is more complicated than condensing boilers, more difficult to install and not really economically worthwhile for small well-insulated homes, so it was considered unlikely that it will be incorporated in Building Regulations before 2030. After consultation with experts, it was decided that the most likely scenario is that dCHP will account for about 10% of gas-heated homes by 2030. It is assumed that heat pumps also have a slow uptake and account for only 10% of electric heating by 2030. Wood is assumed to replace coal and electricity to replace other fuels for heating. Solar thermal is included in regulations for new buildings from 2010, but because of its higher cost solar PV is not included before 2030. It is assumed that most lighting moves to low energy technologies, although demand increases, and electricity demand for lighting falls to 60% of its present level.

Table 2: 'Most Likely' Scenario –Key Model Parameters

Parameters	Scenario 2	Scenario 2 Notes
Demolition	25,000pa across England in proportion to number of dwellings in each region	
Solid Walls	10% insulation to u=0.45 by 2030	
Cavity Walls	90% insulation to u=0.35 by 2030	
Solar PV	Negligible uptake	
Solar Thermal	Uptake equals new build rate from 2010	
Space Heating	dCHP 10% of gas heated homes with >12,000kWhT by 2030; condensing boilers standard from 2005; HP 10% of electrically heated homes by 2030	dCHP 77% heat 15% electricity; condensing boilers 92% efficient HP 350% efficiency
Doors	No change	
Double Glazing	95% installation to u=2.0 by 2030	
Floors	No change	
Air Changes	Gradual improvement to 2030	
Loft Insulation	90% coverage of available. Lofts with less than 200mm increased to 300mm.	New lofts 200mm 1997-2003; 300mm 2004-2030. 3% of pre-1997 lofts upgraded to 300mm each year 2004-2030
Electricity Demand	Lighting Cooking Consumer Electronics White Goods	60% of current 100% of current 200% of current 100% of current
Internal Temperatures	21C in living room and 18C in other rooms	

The minimum efficiency scenario represents what would be likely to happen if the secular trend towards increasing energy efficiency continues, but the increases in energy efficiency programmes between 2005 and 2011 are ineffective, leading to a loss of political will and no extra resources beyond historical levels are committed after 2011.

Since double glazing is driven primarily by factors other than concern about energy efficiency, there is no reason to suppose it would not continue to 95% coverage by 2030 and that draught-proofing will not reach nearly 100%. The uptake of solid wall insulation is not currently subsidised and so it is likely to continue at the present fairly low rate in the absence of further government intervention. If the planned programmes to install cavity wall insulation are not as successful as expected and are not pursued later then uptake of cavity wall insulation may well return to trend and reach only 70% in 2030. Without new effort, loft insulation may remain effectively saturated at 90% and follow the trend in recent years that only 0.5% of lofts are upgrading each year and only to an average of 125mm of insulation (Shorrock and Utley 2003). In this scenario, slow uptake of low energy lighting continues to remain roughly balanced by increased use of lighting. A lack of improvement in efficiency standards leads to an increase in electricity demand for white goods and a greater increase in the electricity demand from consumer electronics.

The change in regulations from 2005 will ensure that nearly all replacement boilers will be condensing boilers. Condensing boilers on the market presently range from 82% to 92% efficient. In this scenario, it is assumed that there are no future improvements to regulations, so the condensing boilers in use will reflect the average efficiency of 87%. In the other two scenarios, it was assumed that by 2030 all boilers are 92% efficient.

In this scenario, it is assumed that the uptake of dCHP and heat pumps is negligible. Neither solar PV nor solar thermal are taken up. Wood is assumed to replace coal and electricity to replace other fuels for heating.

Table 3: Minimum Efficiency Scenario –Key Model Parameters

Parameters	Scenario 3	Scenario 3 Notes
Demolition	25,000pa across England in proportion to number of dwellings in each region	
Solid Walls	10% insulation to u=0.45 by 2030, linear increase	
Cavity Walls	70% insulation to u=0.35 by 2030	
Solar PV	No uptake	
Solar Thermal	No uptake	
Space Heating	No changes to standards after 2005 dCHP and HP negligible	Boilers 87% efficient
Doors	no change	
Double Glazing	95% installation by 2030	Double glazing installed 2004-2030 u=2.0
Floors	No change	
Air Changes	Gradual improvement to 2030	
Loft Insulation	90% coverage.	0.5% p.a existing lofts upgraded to 125mm insulation 1997-2030.
Electricity Demand	Lighting	100% of current
	Cooking	100% of current
	Consumer Electronics	300% of current
	White Goods	150% of current
Internal Temperatures	21C in living room and 18C in other rooms	

Possible changes in incomes

The first English House Condition Survey was undertaken in 1967. Over the years since then average indoor temperatures recorded have increased. That is because of a combination of factors. There have been improvements in home insulation and there has been a transition to the more efficient technology of central heating with North Sea gas. Total household energy consumption rose 27% between 1970 and 2000 (DTI 2001). Real incomes have increased substantially in relation to fuel prices and so households have been able to afford to heat their homes more.

The number of households in fuel poverty has fallen over time largely because real incomes have increased in relation to fuel prices. Most dramatically, the number of people in fuel poverty fell by 40% between 1996 and 2001 mainly as a result of lower fuel prices due to energy market liberalisation and higher incomes (DTI 2003b).

What will happen to incomes is very important for determining what will happen to fuel poverty by 2030. Incomes will be determined both by the level of economic growth experienced and by what happens to levels of inequality. Three socio-economic scenarios were created. It is common for scenarios to be based on the four Foresight scenarios (world markets, global sustainability, national enterprise and local stewardship), but this research follows different assumptions based around policies towards poverty and aimed at producing a best case and a worst case for the incomes of the poorest households in 2030, as well as a 'most likely' scenario.

Advice was sought from Alan Marsh at the Policy Studies Institute, Steve McKay at Bristol University and Mike Brewer at the Institute for Fiscal Studies. All were extremely reluctant to make any prediction for what was likely to happen to income, inequality and the incomes of different kinds of households by 2030. One reason for this may well be that someone in 1978 predicting what would happen to inequality in the UK would probably have expected it to remain about where it was or to continue to decline, as it had been doing for several decades. In fact, the Gini coefficient (the standard international measure of inequality between households, where 0 is complete equality of income and 1 is one household having all the income) increased from 0.25 to 0.34 between 1979 and 1990 (Shepherd 2003). The Gini coefficient stabilised under John Major and fell slightly in 1994-95, before starting to rise very slowly, a trend that continued under the Labour Government, peaking at 0.35 in 2000-01, before falling slightly (ibid).

In 1999, the Prime Minister announced an aim to abolish child poverty by 2020, with poverty defined as living in a household with below 60% of median equivalent income. Equivalent income scales, such as the McClements equivalent income scale, take account of the fact that larger households need a higher income to have the same standard of living as smaller households. Abolishing child poverty according to this definition would be very difficult. However, the IFS think that the Government looks to be on track to reach its interim target of reducing the numbers of children in poverty from its 1997 level of 25% by a quarter in 2004-5 (Brewer 2004). The Government has a further target to reduce child poverty to half its 1997 level by 2010. This is more difficult (the further households are into poverty the more difficult it is to bring them out), but extension of tax credits to do so does not lead to a significant redirection of national income. However, the experts believe that eliminating child poverty would be very demanding because bringing the very poorest families out of poverty would require very large expenditures and they are sceptical that the commitment will be stuck to until 2020. The lowest rates of child poverty in the OECD are in the Nordic countries, where it is 3 to 4% (UNICEF 2000). In the UK, the rate stood at 25% in 1996/7 and 21% in 2002/3 (DWP 2003), among the highest level in OECD countries. The general poverty rate is also 21% at present.

As Alan Marsh (personal communication) pointed out, a problem with focusing exclusively on child poverty is that it can lead to a large difference between the standard of living enjoyed by a household with children and one without children where the parents otherwise earn the same. There is a danger of creating a perverse incentive to have children in order to escape poverty. Indeed, the creation of such large differentials led to the replacement of Working Families' Tax Credit with Working Tax Credit (which those both with and without children are eligible for) and Child Tax Credit.

In order to model incomes, household incomes were first updated from 1996 to 2004. The incomes reported in the 1996 English House Condition Survey, which is the dataset the ECI model is linked to, were compared with the inter-year statistics reported in the Office of National Statistics publication *Households Below Average Income 1994/5-2003/03* (ONS 2004a). Its report on the distribution of income between households (not just those below average income) and how it has changed between years. There are tables based on statistics collected in the Family Resources Survey presenting the changes in income between the different years for different types of households. The population is divided into nine different types of households: pensioner couple, single male pensioner, single female pensioner, couple with children, couple without children, single with children, working age couple without children, single male working age no children, single female working age no children. The changes in median income are reported for each of these groups, for each quintile (fifth) of households adjusted according the McClements equivalent income scale and for households in each of the nine categories according to which quintile they are in. The changes in income are reported both before housing costs (BHC) and after housing costs (AHC). BHC income is more commonly used, but AHC incomes are of course generally lower. Housing makes up a disproportionately large percentage of the expenditure of many poor households, particularly in areas with high housing costs, so poverty rates AHC are higher than poverty rates BHC. *Households Below Average Income* also reports the poverty rates (percentage living on less than 60% of median equivalent income) for children, pensioners and the general population both in BHC and AHC terms.

The incomes in the 1996 English House Condition Survey were updated from 1996 to 2004 by using the Retail Prices Index deflator to allow for inflation and taking the relative changes to median income reported between 1994/5 and 2002/3 (as these were the closest years available) for each category of household and each quintile. It would have been desirable to update both BHC and AHC incomes so as to be able to calculate projected fuel poverty levels in 2030 both BHC and AHC, just as the English House Condition Survey reports fuel poverty both BHC and AHC, although the Government has decided to set its fuel poverty target in terms of income BHC. However, when the results from updating the incomes reported in the 1996 English House Condition Survey were cross-checked with the changes recorded in

Households Below Average Income (ONS 2004a), based on the much more reliable and detailed income data collected in the Family Resources Survey, it was found that although the changes in poverty levels for income BHC of these projections matched closely with the levels in the Family Resources Survey data, they did not for income AHC. The reason for this lay in the unreliability of the calculated income AHC based on the figures in the 1996 English House Condition Survey. The AHC income for many low-income households is very dependent on the values for housing benefit, which are unreliable in the English House Condition Survey. Indeed the survey's electronic user guide says about the housing benefit figures: 'use with caution – there is a lot of imputed data as data missing on rent, whether Housing Benefit and proportion of rent paid by HB.' A number of approaches were tried to attempt to resolve this anomaly, but none were successful. It was decided that any projections of income AHC and hence fuel poverty AHC relying on the data given would be so unreliable as to be misleading. So only income BHC was projected to 2030 and only fuel poverty levels BHC in 2030 were calculated for the different scenarios.

The general level of poverty BHC in 1994/5 was 18%, in 1996/7 it was also 18%, but in 2002/3 it was slightly lower at 17%. The general level of poverty AHC in 1994/5 was 25%, in 1996/7 it was higher at 25%, but in 2002/3 it was lower at 22%. The level of child poverty BHC in 1994/5 was 23%, in 1996/7 it had risen to 25% and by 2002/3 it had fallen to 21%. The level of child poverty AHC in 1994/5 was 32%, in 1996/7 it had risen to 34% and by 2002/3 it had fallen to 29% (ONS 2004a). These falls were due to the increases in benefits and the tax credits, particularly for households with children. The levels of poverty and child poverty BHC that could be calculated from the income data in the 1996 English House Condition Survey closely matched the levels reported by ONS (2004a) from Family Resources Survey data. Incomes were projected forward from 1996 to 2004 by adjusting the incomes for each household by the median change in incomes between 1994/5 and 2002/3 reported in ONS (2004a) for households of the same quintile and the same type. The poverty rate and the child poverty rate projected forward closely matched the reported levels.

The next stage was to project incomes forward from 2004 to 2010. The Government plans to reduce child poverty BHC to half its 1996/7 level by 2010. That means that by 2010 child poverty would be below 12.5%. A tax credit for children was modelled that would achieve this result.

The income scenarios for 2030 were designed with three variables in mind. Firstly, the change in income distribution. Secondly, the rate of economic growth. Thirdly, the increase in the number of households. More households will form if there is higher economic growth, because increased wealth gives more potential households the income to form actual households and because higher economic growth also leads to higher rates of net immigration. The greater number of households somewhat offsets the increase in incomes.

The first scenario devised reduced the level of inequality to around 0.25, its 1979 level in the UK and its current level in the Nordic countries (World Bank 2002). It was decided to first model the effect of tax credits to reach the Government's target to reduce child poverty to half its 1997 level by 2010, which lowered the Gini coefficient from 0.34 to 0.33, and then, because of the unfairness and perverse incentives that would apply if child poverty was largely eliminated but other forms of poverty were not, to postulate for the subsequent years a general tax credit to reduce poverty levels in all kinds of households. The general tax credit was withdrawn at a rate of 18% on income above the poverty level and there was a marginal tax increase of 18% for incomes above the point the tax credit tapered off. This reduced the Gini coefficient to 0.25, the child poverty rate to 2.5% and the general poverty rate to 11%. The poorest 64% of households (those below the mean) were net gainers and the richest 36% of households (those above the mean) were losers. This scenario also assumes a fairly high average rate of economic growth of 2.8% over the next 26 years. The economic scenarios were linked to projections for household numbers and hence the number of new dwellings built by 2030. Higher rates of economic growth were assumed to lead to higher rates of household formation and so larger household numbers as well. The number of households in England in 2030 is 25.40 million.

The second scenario is the 'most likely' one. Because none of the experts would make a commitment as to what was most likely, it was decided to look at history. During the 1960s and 1970s, and again since the early 1990s, inequality remained fairly constant. In this context, the rapid rise experienced in the 1980s was an aberration. It was decided to model the effect of tax credits to reach the Government's target to reduce child poverty to half its 1997 level by 2010, which lowered the Gini coefficient from 0.34 to 0.33 and then keep it constant. The child poverty rate remained at 12.5% and the general poverty rate was 15%. Growth in this scenario was around the long-term average for the UK, at 2.3%. The number of households in England in 2030 is 23.85 million.

The third scenario instead postulated that present policies are kept to until 2010, lowering the Gini coefficient to 0.33, but then there is a significant change of policy and a repeat of the changes in incomes of different parts of the population that happened between 1979 and 1994, with little growth in income for the poorest households and the increased income from economic growth strongly skewed towards the richest households. The rate of child poverty increases to 28% and the general poverty rate to 24%. Following this pattern for the following twenty years to 2030 takes the Gini coefficient from 0.33 to 0.42, the same as the Gini coefficient in the United States in the late 1990s (US Census Bureau 2000). Growth in this scenario was 1.8%, the average growth rate experienced in the UK in the period 1979-95. The number of households in England in 2030 is 22.26 million.

The number of households will also increase over time and the number of homes is assumed to increase to match the number of households. The ECI model built homes to do that in accordance with the kinds of dwellings built in 1991 to 1996. The calculations for increasing numbers of households were already in the ECI model based on the trends in official projections of household numbers to 2021 (DETR 1999), but revised in light of the lower population numbers revealed by the 2001 Census (ONS 2004b). It would have required reprogramming of the ECI model to use different estimates and a shortage of time for the ECI programmer meant that it was decided to use existing projections. The central projection was for 23.85 million households in England in 2030. The rate of household formation was also assumed to be higher than trend in the higher growth scenario and lower than trend in the lower growth scenario. There were 6.5% more households than trend in 2030 with high economic growth (25.40 million households) and 6.7% fewer households than trend with low economic growth (22.26 million households). These differences were taken into account in the calculation of incomes. The incomes of households living in homes built after 1996 were calculated by matching them with the income projected to 2030 of the household living in the most similar existing home in terms of region, type of dwelling, tenure and floor area.

There will be other demographic changes by 2030, but it was decided that attempting to explicitly incorporate them into the model would confuse matters. The proportions of pensioners and single adults are expected to increase and the proportion of couples with children is expected to decrease. The difficulty in adjusting incomes to allow for the changes in the proportions of the different kinds of households to improve the accuracy of the projections is that those households would have to be matched to dwellings and the kind of households that will live in particular dwellings by 2030 will also have changed. What is unlikely to change much is the relative ranking of the incomes of households that live in particular types of dwellings since that is largely what determines what kind of home households can afford.

The *total* national household income in the high income scenario is 13.5% higher than in the medium income scenario and the *total* national household income in the low income scenario is 12.0% lower than in the medium income scenario (1.135 and 0.880 are almost exactly reciprocal). But because the number of households is 6.5% higher than the central projection in the high income scenario and 6.7% lower than the central projection in the low income scenario, the *average* income of households in the high income scenario is only 6.6% higher than in the medium income scenario and the *average* income of households in the low income scenario is only 5.7% lower than in the medium income scenario. The way in which the different income scenarios really vary is in the income *distribution*. The median income of the bottom quintile (the poorest 20% of households) in the low income (and increased inequality) scenario is 12.8% lower than in the medium income scenario. The difference is even bigger in the high income (and decreased inequality) scenario. The median income of the bottom quintile in the high income scenario is 36.6% higher than in the medium income scenario. The reason why the difference in the incomes of the poorest from the medium incomes scenario is so much greater in this scenario than in the low income scenario is because in the low income scenario there has simply been a bias for added income for economic growth to go to the rich, whereas in the high income scenario the poorest households have been targeted for the most assistance through tax credits. The effect of this will be seen in the results section.

Possible changes in energy prices

Around 80% of British homes are now heated by North Sea gas. North Sea gas is also the primary fuel for electricity production. Yet it will be largely exhausted in a couple of decades' time. Britain is likely to become increasingly dependent on gas from Russia and the Middle East (Strategy Unit 2002), which have three-quarters of proven world reserves. Indeed, 58% of the world's reserves of natural gas lie in just three countries, Russia, Iran and Qatar (Energy Information Administration 2004). The Energy White Paper (DTI 2003a) was relaxed about the implications of natural gas providing not just most of our heating, but an increasingly dominant proportion of our electricity as well.

The scenarios in this area drew in particular on the results of models presented in two publications, the *World Energy, Technology and Climate Policy Outlook 2030* (European Commission 2003), the report of a European research project known as WETO, and *Options for a Low Carbon Future* (DTI 2003c), a report for the DTI's preparation of the Energy White Paper. Both these reports contained projections of future energy costs under different scenarios.

The WETO report looked at likely and possible changes to the price of gas on the European market as part of a much broader analysis of the trajectory of the global energy system. They assumed a largely 'business as usual' development of world energy demand to 2030. Global demand is double its 1990 level by 2030 and carbon constraints are not observed. The US increases its carbon dioxide emissions by 50% from 1990 levels and the EU by 18%. The predictions for energy reserves are based on US Geological Survey (2000) estimates, which have been criticised as possibly over-optimistic. The WETO report also gives 5% and 95% confidence limits for oil and gas reserves. It predicts that by 2030, North Sea gas reserves will be exhausted. Norway will produce gas in the Norwegian Sea, but the largest share of Europe's gas will come from Russia. Russia and the Persian Gulf region between them have 68% of the world's existing gas reserves. In 2030, Russian gas will be supplemented with pipeline gas from Norway, Algeria and Libya and some from the Persian Gulf (through Turkey). Liquefied natural gas (LNG) from the Persian Gulf and Nigeria will also be used.

A detailed assessment of world hydrocarbon reserves (International Energy Agency 2001) pointed out that existing fields in western Siberia, the mainstay of Russian production, are declining rapidly. The International Energy Agency expressed some concern about the future of Russian gas production. Russia has other gas reserves that have not yet been developed outside western Siberia. There are reserves in the Arctic under the Yamal Peninsula (which juts north into the Kara Sea east of Novaya Zemlya) and some in the Barents Sea, although both would be expensive to develop and are not expected on stream before 2015. Gas from the Persian Gulf would actually be cheaper on the European market, despite the additional distance. There are also reserves around Astrakhan. It is believed that Russia has large undiscovered reserves of gas elsewhere. Russia and the other countries of the former Soviet Union have 58 trillion cubic metres (tcm) of proven reserves and an estimated 44 tcm of undiscovered reserves (International Energy Agency 2001).

The Persian Gulf area is the other part of the world with really large gas reserves. It has 58.5 tcm of proven reserves and it is believed to have 115-136 tcm of ultimate reserves (International Energy Agency 2001). Because of its distance from major gas markets, gas production there has been low in relation to the size of reserves and it will still be providing gas long after Russia's resources are depleted.

World gas reserves are more widely dispersed than world reserves of conventional. The major difference is that rather than being concentrated in the Middle East, like oil reserves, gas reserves are concentrated in the Middle East and Russia. It has been argued that a cartel would be unable to drive up the price of natural gas as OPEC in the past did with oil, because Russian gas could be obtained instead. However, this seems to overlook the possibility that Russia and the OPEC nations could get together to form a cartel.

There has been discussion recently about ‘peak oil’, the heretical (in the energy industry) theory that oil production will peak between 2005 and 2010. The USGS instead predicts that oil production will continue to increase until after 2035. Supporters of the ‘peak oil’ theory argue that officially-stated oil reserves have been overestimated by OPEC members to boost their production quotas (which are based on their stated oil reserves) and outside OPEC by private oil companies to boost their share price. They point out that globally oil discoveries peaked in the early 1960s and the fields discovered then should be expected to start to decline, just as oil discoveries in the United States peaked in 1930 and oil production peaked in 1972. Oil extraction has been greater than oil discovery every year since 1980 (Aleklett and Campbell 2003). Their critics argue that extraction techniques are continually improving, meaning that more oil is being extracted from old discoveries and that non-conventional sources of oil, such as the oil shale found in western Canada and the tar sands in eastern Venezuela, will be used increasingly as conventional oil runs out. ‘Peak oil’ proponents respond that revising estimates for recoverable reserves because of the ability to extract a higher proportion of oil from a field is not really a new discovery and treating it that way disguises the decline in actual discoveries over the years. They also express scepticism about large-scale extraction of oil from oil shale and tar sands as they would require enormous amounts of energy and water.

Although ‘peak oil’ proponents claim that gas reserves have also been overestimated, they believe that ‘peak gas’ will come much later, about 2030 (Laherrere 2004). However, because gas can substitute for oil in many cases, if ‘peak oil’ is correct, the price of gas will rise significantly in future.

The gas price fluctuates in response to the oil price, although not as much, and unlike oil prices, gas prices vary significantly between different regions of the world as gas is not as readily transported. The WETO report’s projections for the prices of oil and gas in 2004 were €20 ($24) per barrel of oil and on the European market €13 ($16) per barrel of oil equivalent of gas. That price of gas translates to 15p/therm. The actual price of oil at the time of writing (September 2004) is about $45 a barrel and the price of October gas (the benchmark) is about 32p/therm. However, oil prices are 50% above their level a year ago and gas prices are 40% above their level a year ago. Only five years ago, the price of oil was $10 a barrel. This shows how volatile the prices of oil and gas are in the short term and how unreliable predictions are.

The WETO report gives three predictions for the prices of oil and gas in 2030. One is a central prediction, based on the USGS estimates for ultimately recoverable resources of oil and gas globally. It also gives price predictions based on a low estimate and a high estimate (supposedly within 95% confidence intervals) for ultimately recoverable resources of oil and gas. In the low case, oil resources are only 79% of the USGS central estimate and gas resources are only 74% of the USGS central estimate. In the high case, oil resources are135% of the USGS central estimate and gas resources are 144% of the USGS central estimate.

The WETO report predicts that in the central case, the price of oil in 2030 will be €35 ($42) per barrel and the price of gas on the European market will be €28 ($34) per barrel of oil equivalent, which works out at 32p/therm. As noted above, oil and gas are at that level in 2004. In the low resources (high price) case, the price of oil will be

€42 ($50) per barrel and the price of gas will be €36 ($43) per barrel of oil equivalent, which works out at 41p/therm. In the high resources (low price) case, they do not use the high oil resources estimate, substituting the central estimate for reasons that are not explained, but they predict that the price of gas on the European market will be €20 ($24) per barrel of oil equivalent, which works out at 23p/therm.

These predictions imply that the price of energy in 2030 is unlikely to be much higher than it is now. These figures are the only recent prediction of prices in 2030 available that looks at reserves and applies a model of the energy market to them, so they have been treated as the most widely accepted estimates available, despite criticism that they are over-optimistic because they rely on USGS estimates which hold that neither oil nor gas are in short supply.

World gas production is currently about 100 trillion cubic feet (Tcf) per annum (or 16 billion barrels of oil equivalent). Laherrere (2004) translates WETO's central estimate for world gas production in 2030 as 190 Tcf per annum (or 30 billion barrels of oil equivalent) and still rising rapidly. His estimate, based on following a Hubbert curve extrapolating a curve from historical gas production data and where gas production peaks about sixty years after gas discoveries peaked, is that world gas production will peak around 2030 at 140 Tcf (22 billion barrels of oil equivalent). Laherrere predicts that gas production from Russia and the rest of the former Soviet Union will peak around 2015, while gas production from the Middle East will peak between 2030 and 2040.

The 140 Tcf estimate is only slightly lower than WETO's low reserves estimate for gas, but even WETO's low estimate for oil reserves assumes that oil is substantially more abundant than the supporters of the 'peak oil' theory hold. The USGS holds that there are about 3 trillion barrels of oil left and oil production will not peak until the 2030s, and at minimum about 2.4 trillion barrels of oil left; the 'peak oil' school of thought holds that there are less than 1 trillion barrels of oil left. Following a Hubbert curve for oil that peaks in 2010 at about 27 billion barrels of oil per annum, oil production would fall to about 15 billion barrels of oil per annum by 2030 (Aleklett and Campbell 2003) while gas production would be at 22 billion barrels of oil equivalent in 2030 (Laherrere 2004). Following WETO estimates, however, world oil production will increase to about 44 billion barrels of oil per annum in 2030 while gas production will be about 30 billion barrels of oil equivalent.

That means that production of the two forms of energy together is 74 billion barrels of oil equivalent in the WETO scenario and 37 billion barrels of oil equivalent in Campbell and Laherrere's scenario. Given that energy demand in the long term is highly elastic to price - as DTI (2003c) assumes in their calculations. If Laherrere is correct in his analysis of the true availability of oil and gas and it is assumed that gas cannot substitute for oil then oil prices in 2030 would be about three times as high as they are in WETO's central projections at €103 ($123) per barrel of oil, while prices for gas would be only 35% higher at €38 ($46) per barrel of oil equivalent, or 43p/therm. However, gas can be substituted for oil for many uses and inevitably that would happen as far as possible if oil production were to fall 40% by 2030 and the price was to rise very substantially. Since about 50% of the oil used in the world is for transport, for which it would be impractical to rapidly substitute natural gas for oil, that would mean that other uses of oil would have to decrease very dramatically, which would be more difficult for countries that are currently very dependent on oil and far from supplies of natural gas. However, the development of liquid natural gas (LNG) tanker ships is anyway taking such countries (for example in East Asia) in the direction of greater use of natural gas. Simple substitution would imply that the price of both oil and natural gas would be around twice what it is now, giving a price of oil of €70 ($84) per barrel and a price of gas of €56 ($67) per barrel of oil equivalent, or 64p/therm. It was assumed that some substitution would take place and the prices would be about halfway between the two extremes, reflecting the fact that about half of world oil consumption is for transport purposes, where substitution with natural gas is much more difficult than for stationary uses. The price of oil would therefore be about €86 ($103) per barrel and the price of gas would be about €47 ($56) per barrel of oil equivalent, or 53p/therm. It was decided to use these very rough estimates, rather than WETO's 'high price' scenario, for the high energy price scenario in order to better reflect the genuine uncertainty.

To translate these prices into estimates for British consumer energy prices in 2030, it is necessary to turn to the predictions in DTI (2003c). The domestic price to the consumer in 2000 was 50.0p/therm, while the industrial price was 21.5p/therm and the price to the electricity supply industry was 23.0p/therm. In their predictions of future prices to 2050, the absolute differences between these prices remains constant. In the baseline scenario they predict the price will rise 6.7p/therm from 2000 levels by 2030. This is lower than the WETO central prediction, but it is arrived at by different and even less reliable means, looking only at demand and ignoring supply, although their baseline prediction for 2040 and their Global Sustainability prediction for 2030 (10p/therm above 2000 levels) almost exactly match the WETO central prediction for 2030. WETO's low prediction for 2030 is only slightly higher than actual 2000 prices. We can calculate that the central estimate for the price of gas to the British consumer in 2030 is 60p/therm, or 2.05p/kWh. The low estimate is 51p/therm, or 1.74p/kWh. The high estimate is 81p/therm, or 2.76p/kWh. In all the calculations, standing charges were not included as they unnecessarily complicate matters, increasing bills for low users and decreasing bills for high users.

The MARKAL model estimates that the combined cost of electricity for industrial users in 2020 with the EU emissions trading scheme and meeting the 20% renewables target for that year is equivalent to the cost of electricity meeting a 20% carbon dioxide reduction target and stands at £12.10/GJ or 5.11p/kWh, compared to 4.36p/kWh for the baseline scenario and rises to £12.70/GJ or 5.36p/kWh in 2050 (DTI 2003c). MARKAL estimates the cost of electricity in 2020 with a 30% reduction in carbon dioxide emissions is 5.94p/kWh, but the cost to achieve that result in 2030 would be lower because technology would have moved on – the price is only very slightly higher at 6.01p/kWh for a 60% reduction in 2050. The price of electricity for industrial users in 2003 was 3.10p/kWh and for domestic users it was 6.75p/kWh (DTI 2004). In the absence of a figure for the baseline cost of electricity in 2030, the most reasonable baseline figure to use for 2030 seems to be an interpolation between the cost in 2020 including emissions trading and the renewables obligation (5.11p/kWh for industrial users) and the cost in 2050 with no additional constraints (5.36p/kWh for industrial users). That would be 5.19p/kWh for industrial electricity and 8.84p/kWh for standard rate domestic electricity.

However, the baseline cost of gas in 2030 in MARKAL is 3.3p/therm (or 0.11p/kWh) lower than assumed here. Combined cycle gas turbines are projected to be 68% efficient in 2030. Since gas accounts for 85% of electricity production in 2030 in the baseline model, the industrial price of electricity in our baseline scenario would be 0.14p/kWh higher at 5.50p/kWh and the price for standard rate domestic electricity would be 9.15p/kWh.

A higher gas price would make electricity from gas even more expensive and in the high energy cost scenario the cost of electricity from gas would be 0.89p/kWh higher, but since in MARKAL electricity from gas costs about 2.1-2.3p/kWh to generate in 2030 and other kinds of electricity cost 2.5p/kWh to 3.5p/kWh to generate, an increase of that magnitude could make gas less competitive for electricity and other technologies costing on average only 3p/kWh would predominate, according to MARKAL. In reality, some substitution would take place, but the costs of renewable energy increase as a larger proportion of demand is met from it as there needs to be a larger and larger amount of conventional generation as back-up for when intermittent renewables fail to generate enough electricity and the reintroduction of coal seems unlikely because of the carbon emissions impact. As a worst case, it is assumed that electricity would be 0.89p/kWh more expensive than in the middle price scenario and the cost of industrial electricity would be 6.39p/kWh and standard rate domestic electricity would be 10.04p/kWh.

Conversely, if the price of gas was lower, no more gas would be used than in the baseline scenario as the non-gas electricity production is entirely a consequence of the renewables obligation and Sizewell B remaining in operation. In the low energy price scenario, the cost of industrial electricity would be about 0.39p/kWh cheaper than in our middle price scenario at 5.11p/kWh and 8.76p/kWh for domestic electricity.

These figures are for standard rate electricity. In 1996, 2.5% of households used standard rate electricity for heating and 8.4% used off-peak electricity for heating (DETR 2000), so 77% of the 10.9% that were electrically heated used off-peak electricity for heating. Among electrically heated households, being on an off-peak electricity tariff strongly correlates with greater use, so off-peak electricity's proportion of the electricity used for heating is higher, but difficult to quantify due to limitations in the data. At present, off-peak electricity costs around 2.70p/kWh. Assuming 90% of electricity for heating is off-peak and 10% peak, that gives an average price of about 3.10p/kWh - the same as industrial users pay. It is assumed that off-peak electricity will continue to be provided and the average cost of electricity for heating is the same price as industrial electricity – 5.11p/kWh in the low cost scenario, 5.50p/kWh in the baseline scenario and 6.39p/kWh in the high cost scenario. Where homes have heat pumps by 2030, it is assumed that the electricity running them is standard rate as heat pumps cannot efficiently run storage heaters.

The price of wood was the same in all three scenarios, the present price of 2.5p/kWh for bagged wood pellets.

Different climate change scenarios would also have an effect on price. In a world with only moderate warming (1°C by 2030) the effect of climate change on energy prices would be modest. If the THC closed down, temperatures in north-west Europe would be about 2°C cooler than in 1960-1990, but temperatures globally would only fall back by 1°C to their 1960-1990 levels. Since by 2030 gas will be a rather globalised commodity, the effect would be similarly modest. If there was rapid warming by 4°C globally, that would be 3°C warmer than the most likely level of warming and reduce the demand for heating. The effect on the price of gas is difficult to determine, because to calculate it would require information about the effect on heat demand at a global level. It is also likely that gas will be used for an increasingly wide variety of purposes as well as heating. After examination, it was decided that the effect would probably be small compared to the large variations already allowed for.

The same objection could be made about the interaction between other dimensions of the scenarios. The philosophy underlying this research has always been to make the scenarios independent. There are two reasons for that. The first is that if the scenarios are adjusted before they go into the model then the way that different factors affect the results that come out is obscured and they would become difficult to understand. The second is that individually crafting 81 scenarios would be an unreasonable amount of effort in such a small project, particularly in one that was also limited in its access to the ECI computer model and the time of their programmer.

Table 4: Cooling Scenarios

	Energy Efficiency	Growth/ Distribution	Energy price	CO_2 emissions (million tonnes)	% change emissions since 1990	£ Billion domestic energy	Fuel poor households	% fuel poor households
1	High	High	High	83.47	-33.2	21.58	125,000	0.5
2	High	High	Medium	83.47	-33.2	18.46	50,000	0.2
3	High	High	Low	83.47	-33.2	17.09	25,000	0.1
4	High	Medium	High	79.02	-36.8	20.38	825,000	3.4
5	High	Medium	Medium	79.02	-36.8	17.42	475,000	2.0
6	High	Medium	Low	79.02	-36.8	16.13	350,000	1.5
7	High	Low	High	76.09	-39.1	19.44	1,650,000	7.4
8	High	Low	Medium	76.09	-39.1	16.59	1,200,000	5.3
9	High	Low	Low	76.09	-39.1	15.35	1,000,000	4.5
10	Medium	High	High	124.09	-0.7	27.39	725,000	2.9
11	Medium	High	Medium	124.09	-0.7	22.75	350,000	1.4
12	Medium	High	Low	124.09	-0.7	20.72	225,000	0.9
13	Medium	Medium	High	121.91	-2.5	26.63	1,800,000	7.6
14	Medium	Medium	Medium	121.91	-2.5	22.07	1,100,000	4.6
15	Medium	Medium	Low	121.91	-2.5	20.08	850,000	3.6
16	Medium	Low	High	115.93	-7.3	25.22	2,750,000	12.3
17	Medium	Low	Medium	115.93	-7.3	20.88	1,900,000	8.5
18	Medium	Low	Low	115.93	-7.3	18.99	1,600,000	7.2
19	Low	High	High	144.18	+15.3	32.73	1,250,000	4.9
20	Low	High	Medium	144.18	+15.3	27.34	625,000	2.4
21	Low	High	Low	144.18	+15.3	24.98	400,000	1.6
22	Low	Medium	High	139.74	+11.8	31.47	2,600,000	10.8
23	Low	Medium	Medium	139.74	+11.8	26.25	1,700,000	7.1
24	Low	Medium	Low	139.74	+11.8	23.96	1,350,000	5.6
25	Low	Low	High	133.60	+6.9	29.91	3,800,000	17.0
26	Low	Low	Medium	133.60	+6.9	24.92	2,700,000	12.1
27	Low	Low	Low	133.60	+6.9	22.73	2,250,000	10.2

Figure 1: CO_2 emissions (million tonnes) in cooling scenarios

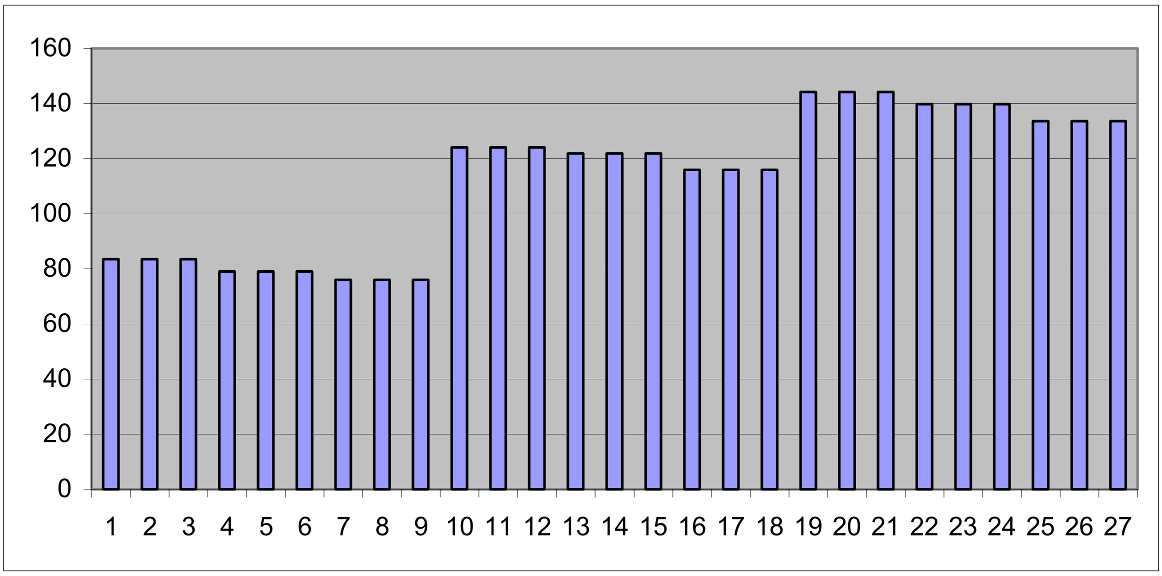


Figure 2: Percentage of fuel poor households in cooling scenarios

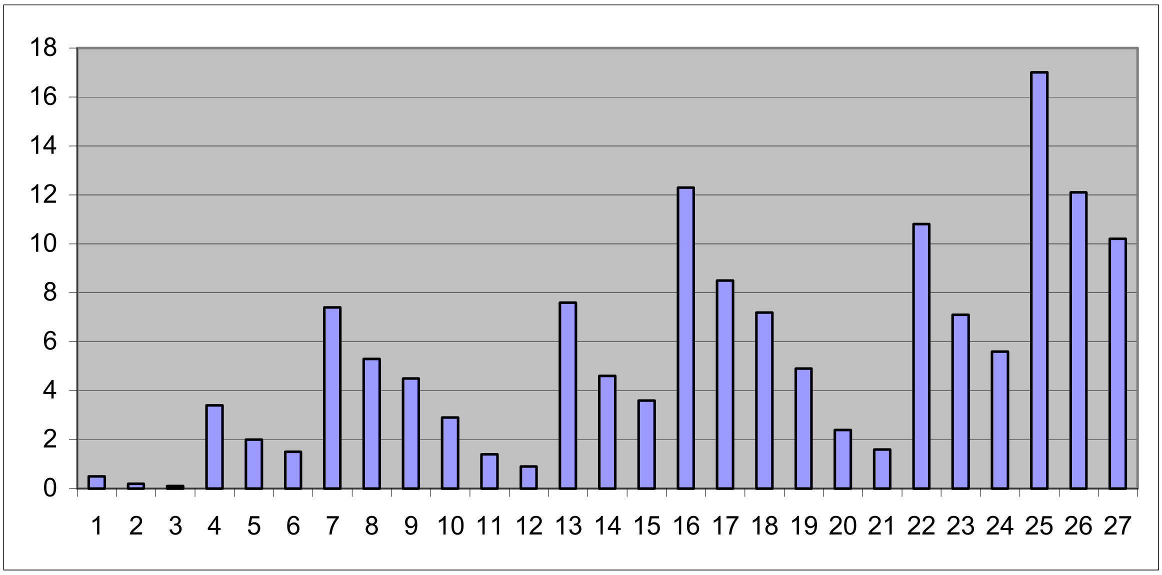


Table 5: Moderate Warming Scenarios

	Energy Efficiency	Growth/ Distribution	Energy price	CO_2 emissions (million tonnes)	% change emissions since 1990	£ Billion domestic energy	Fuel poor households	% fuel poor households
1	High	High	High	68.78	-45.0	19.14	50,000	0.2
2	High	High	Medium	68.78	-45.0	16.57	<25,000	<0.1
3	High	High	Low	68.78	-45.0	15.44	<25,000	<0.1
4	High	Medium	High	65.07	-47.9	18.06	525,000	2.2
5	High	Medium	Medium	65.07	-47.9	15.62	300,000	1.3
6	High	Medium	Low	65.07	-47.9	14.56	250,000	1.0
7	High	Low	High	62.32	-50.1	17.17	1,275,000	5.7
8	High	Low	Medium	62.32	-50.1	14.84	950,000	4.3
9	High	Low	Low	62.32	-50.1	13.82	825,000	3.7
10	Medium	High	High	96.95	-22.4	22.87	300,000	1.2
11	Medium	High	Medium	96.95	-22.4	19.24	125,000	0.5
12	Medium	High	Low	96.95	-22.4	17.66	75,000	0.3
13	Medium	Medium	High	94.67	-24.3	22.09	1,075,000	4.5
14	Medium	Medium	Medium	94.67	-24.3	18.55	650,000	2.7
15	Medium	Medium	Low	94.67	-24.3	17.00	500,000	2.0
16	Medium	Low	High	89.92	-28.1	20.89	1,925,000	8.6
17	Medium	Low	Medium	89.92	-28.1	17.52	1,575,000	6.2
18	Medium	Low	Low	89.92	-28.1	16.05	1,325,000	5.3
19	Low	High	High	115.19	-7.8	27.93	625,000	2.4
20	Low	High	Medium	115.19	-7.8	23.62	275,000	1.1
21	Low	High	Low	115.19	-7.8	21.73	175,000	0.7
22	Low	Medium	High	111.19	-11.0	26.74	1,725,000	7.3
23	Low	Medium	Medium	111.19	-11.0	22.58	1,125,000	4.7
24	Low	Medium	Low	111.19	-11.0	20.76	850,000	3.6
25	Low	Low	High	106.03	-15.2	25.35	3,525,000	15.9
26	Low	Low	Medium	106.03	-15.2	21.38	2,350,000	10.5
27	Low	Low	Low	106.03	-15.2	19.65	1,850,000	8.3

Figure 3: CO_2 emissions (million tonnes) in moderate warming scenarios

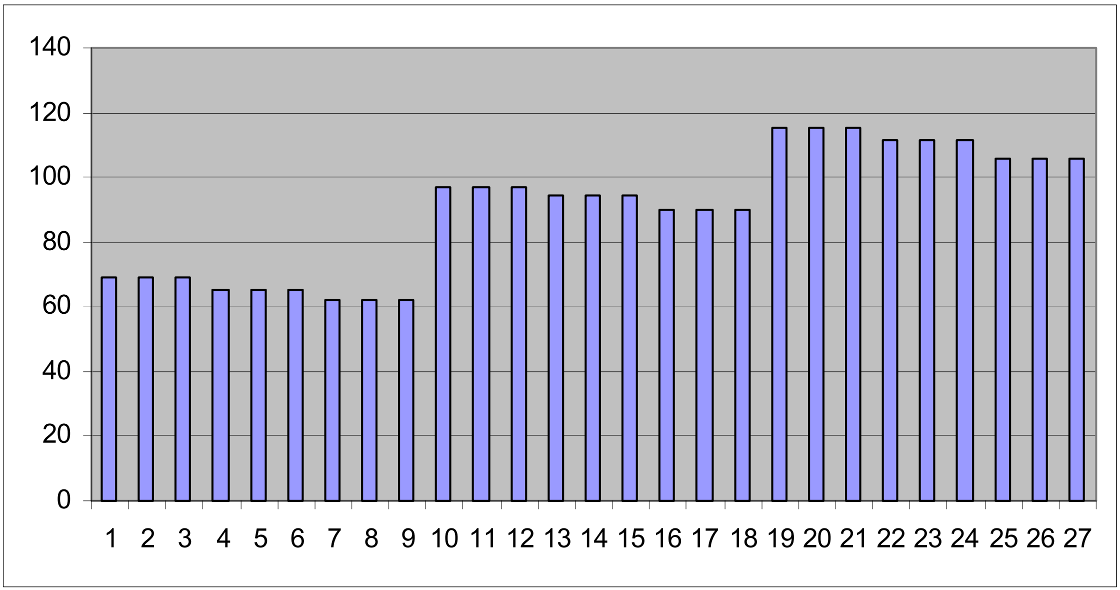


Figure 4: Percentage of fuel poor households in moderate warming scenarios

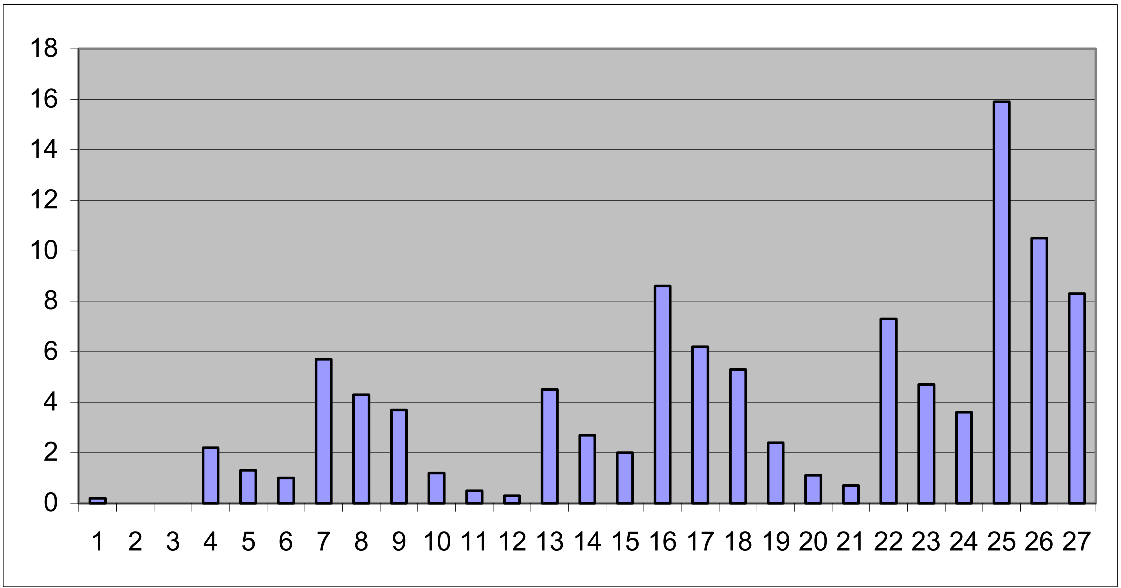


Table 6: High Warming Scenarios

	Energy Efficiency	Growth/ Distribution	Energy price	CO_2 emissions (million tonnes)	% change emissions since 1990	£ Billion domestic energy	Fuel poor households	% fuel poor households
1	High	High	High	59.23	-52.6	17.46	<25,000	<0.1
2	High	High	Medium	59.23	-52.6	15.24	<25,000	<0.1
3	High	High	Low	59.23	-52.6	14.27	<25,000	<0.1
4	High	Medium	High	55.98	-55.2	16.47	350,000	1.5
5	High	Medium	Medium	55.98	-55.2	14.37	225,000	1.0
6	High	Medium	Low	55.98	-55.2	13.46	175,000	0.8
7	High	Low	High	53.31	-57.4	15.59	1,050,000	4.7
8	High	Low	Medium	53.31	-57.4	13.59	775,000	3.5
9	High	Low	Low	53.31	-57.4	12.72	700,000	3.2
10	Medium	High	High	78.67	-37.1	19.83	125,000	0.5
11	Medium	High	Medium	78.67	-37.1	16.89	50,000	0.2
12	Medium	High	Low	78.67	-37.1	15.57	25,000	0.1
13	Medium	Medium	High	76.29	-39.0	19.04	675,000	2.8
14	Medium	Medium	Medium	76.29	-39.0	16.18	400,000	1.6
15	Medium	Medium	Low	76.29	-39.0	14.93	300,000	1.3
16	Medium	Low	High	72.32	-42.1	17.96	1,450,000	6.5
17	Medium	Low	Medium	72.32	-42.1	15.26	1,050,000	4.7
18	Medium	Low	Low	72.32	-42.1	14.07	900,000	4.0
19	Low	High	High	95.76	-23.4	24.71	300,000	1.2
20	Low	High	Medium	95.76	-23.4	21.12	125,000	0.5
21	Low	High	Low	95.76	-23.4	19.56	75,000	0.3
22	Low	Medium	High	91.98	-26.4	23.56	1,200,000	5.1
23	Low	Medium	Medium	91.98	-26.4	20.12	750,000	3.2
24	Low	Medium	Low	91.98	-26.4	18.61	575,000	2.4
25	Low	Low	High	87.44	-30.0	22.27	2,175,000	9.8
26	Low	Low	Medium	87.44	-30.0	19.00	1,550,000	6.9
27	Low	Low	Low	87.44	-30.0	17.57	1,350,000	6.0

Figure 5: CO_2 emissions (million tonnes) in high warming scenarios

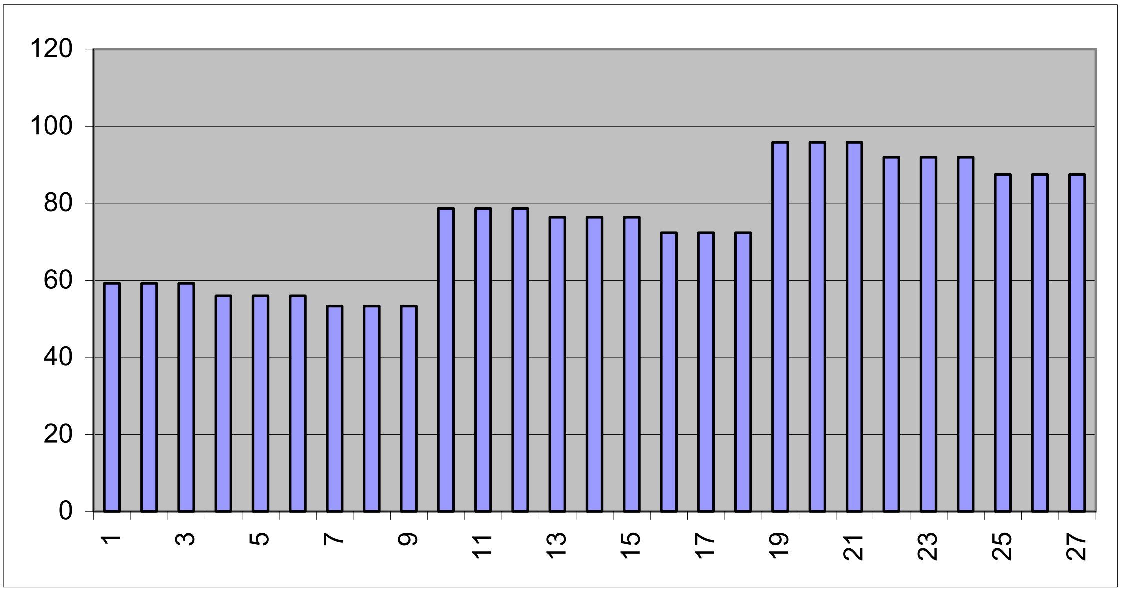
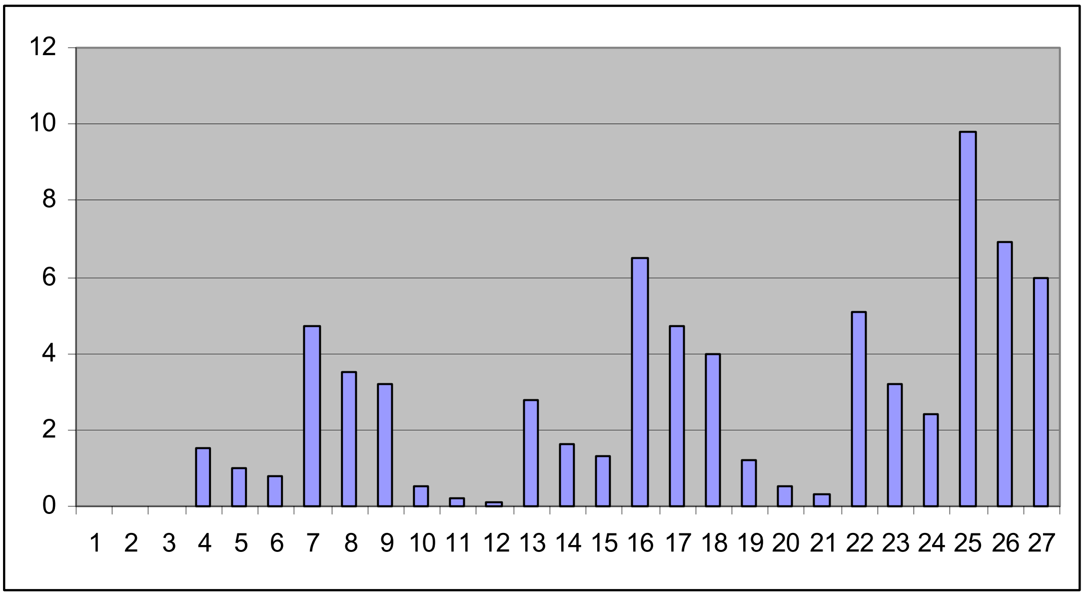


Figure 6: Percentage of fuel poor households in high warming scenarios



Results

The results of the 81 scenarios are presented here in three large tables, one table for each set of climate scenarios. Table 4 presents the cooling scenarios and Figures 1 and 2 provide graphical representations. Table 5 presents the moderate warming scenarios and Figures 3 and 4 provide graphical representations. Table 6 presents the high warming scenarios and Figures 5 and 6 provide graphical representations. Numbers have been rounded and the estimates for the numbers of households in fuel poverty have been rounded to the nearest 25,000 (about 0.1% of households).

It is important to note that the emissions given are not predictions of actual emissions under the scenarios, but of the emissions that would occur if all homes were heated to exactly the standard heating regime.

There is a huge amount of variation between the different scenarios. Emissions range from 53.31 million tonnes of carbon dioxide, a reduction of 57.4% from 1990 levels of 125 million tonnes, and an expenditure on domestic energy of £12.72 billion per annum up to emissions of 144.18 million tonnes of carbon dioxide, an increase of 15.3% from 1990 levels, and an expenditure of £32.73 billion per annum. The numbers of households in fuel poverty range from a few thousand households to 3.8 million households, more than twice the 1.7 million in 2001. The possibility space is enormous.

The reason for the reduction in carbon emissions in most of the scenarios is not simply because of increased efficiency in the use of energy, it is also because of less carbon-intensive electricity production. With the complete phasing out of coal for electricity production by 2030, a shift to very efficient combined cycle gas turbines and an expansion of renewable energy to take much of the place of nuclear power, carbon dioxide emissions per kilowatt-hour have fallen from 0.43kg/kWh now to just 0.24kg/kWh in 2030. Indeed, it is the fall in the carbon intensity of electricity production that accounts for the large reductions in carbon emissions. If the carbon intensity of electricity production had remained the same as it is now, carbon emissions in all the scenarios would be about 20% higher in relation to 1990 levels.

Of course, not all the scenarios are equally likely. Scenarios closer to the central one are generally more likely than scenarios further away. Scenarios which involve a combination of extreme scenarios are particularly unlikely. The purpose of this project is not to predict what will happen, but to create a wide range of scenarios of what might happen, some of them very improbable, in order to explore the possibility space and the relative significance of the variations in the different dimensions that influence fuel poverty.

It is worth noting first that the central scenario, the one which is most likely of the 81, with moderate warming, medium efficiency improvements, medium growth and little change in income distribution, and medium energy prices shows a decrease in emissions compared to 2001 levels of 24% or about 30.5 million tonnes of carbon dioxide, far short of the interim target of a 40% reduction by 2030, and a 62% decrease in fuel poverty from 1.7 million households in 2001 to 650,000 households (2.7%), a very long way short of the target of abolition by 2016. Consumer energy prices have risen significantly in this scenario, but even in the relatively low cost scenario where gas costs only about the same as it cost in 2000 and electricity prices have risen by 'only' 2.01p/kWh, fuel poverty has only fallen to 500,000 households (2.0%), about 71% down on 2001 levels, but still quite a long way short of abolition. It seems that policies for achieving the target of the abolition of fuel poverty may rest on the assumption that energy prices are not going to rise.

The rise in electricity prices used in the scenarios based on the projections by DTI (2003c) plays the main role in the relatively poor performance on fuel poverty in even the low energy price scenarios. In those scenarios, it is assumed that the price of gas is going to stay about the same as was in 2000, but the standard rate electricity price still increases by 2.01p/kWh from 6.75p/kWh to 8.76p/kWh. Since the average electricity bill for light and power in a gas-heated home is about £200 a year, that increase means that the electricity bill goes up by about £60 to £260, which is not insignificant when you consider that the average saving from cavity wall insulation is about £100 a year. Under the medium price assumption, where the price of standard rate electricity is 9.15p/kWh, the increase in a £200 electricity bill is £70, to £270. Under the high price assumption, where the price of standard rate electricity is 10.04p/kWh, the increase in a £200 electricity bill is nearly £100, to about £300.

What is more, the increase in the price of electricity affects electrically-heated homes particularly badly. They have an increase in the average price of heating for homes with off-peak electricity from about 3.10p/kWh to 5.11p/kWh, a 65% increase –and that is the low cost assumption. The medium cost assumption is an increase of 77% to 5.50p/kWh and the high cost assumption is an increase of 106% to 6.39p/kWh. Electrical heating becomes much more expensive than it is now. By comparison, the cost of gas does not increase so much. In the low price projection, it is 1.74p/kWh, an insignificant 2% increase on the 2000 price of 1.71p/kWh. In the medium price scenario, it is 2.05p/kWh, a 20% increase on 2000 prices. There is only a large price rise in the high price scenario, where it is 2.76p/kWh, a 61% increase.

There is a caveat to the Government's fuel poverty commitment – fuel poverty is to be abolished 'as far as reasonably practical'. What does that mean? The medium efficiency scenario was designed to achieve about 95% implementation of all the standard energy efficiency measures (central heating, loft insulation, cavity wall insulation where there are cavities), regarded as near saturation level, and 10% implementation of the more ambitious measures (solid wall insulation, dCHP and heat pumps). Under the high efficiency and medium income scenario with moderate warming, where all the measures are pursued to 100%, fuel poverty levels are only about half as high and emissions are 31.3% lower, having fallen by 47.9% compared to 1990 levels, not just 24.3%. The question is whether the more ambitious measures be implemented almost universally by 2030.

However, in order to bring fuel poverty numbers down close to negligible levels in the moderate warming or even the high warming scenarios, it is necessary to boost the incomes of the poor through Scandinavian-style redistribution. At this point, it should be mentioned that incomes reported in the EHCS differ from those in income surveys such as the Family Resources Survey because although some respondents report extremely low incomes, in EHCS they are always increased to equal what a household of that composition would receive on means-tested benefits. However, this does not entirely resolve the problem of under-reporting of income in surveys by some of the self-employed. It should be borne in mind that some of the fuel poverty shown in the tables could be an artefact of households which in fact have higher incomes being treated as though they live on means-tested benefits.

Comparing how the different dimensions of the scenarios interact, there is more fuel poverty with low energy efficiency and high incomes than with high energy efficiency and low incomes. However, medium energy efficiency and high incomes lead to less fuel poverty than high energy efficiency and medium incomes, although medium energy efficiency and low incomes lead to more fuel poverty than low energy efficiency and medium incomes.

Fuel poverty levels are much lower in scenarios with high incomes and high energy prices than in otherwise equivalent ones with low incomes and low energy prices. In fact they are lower than in otherwise equivalent scenarios with medium incomes and low prices. Fuel poverty levels are about the same in scenarios with medium incomes and high prices as in otherwise equivalent scenarios with low incomes and low prices. This shows that the variation in incomes has more impact on fuel poverty than the variation in prices.

There is much less fuel poverty with high incomes and cooling than with low incomes and high warming. There is even much less fuel poverty with cooling and medium incomes than with rapid warming and low incomes. There is slightly less fuel poverty with cooling and high incomes than with rapid warming and medium incomes. The variation in incomes has much more impact on the levels of fuel poverty than the variation in temperatures.

Fuel poverty is about the same in scenarios with cooling and low energy prices as in scenarios with high warming and high energy prices. Fuel poverty is lower with high warming and medium prices than with moderate warming and low prices, while cooling and medium prices lead to about the same amount of fuel poverty as moderate warming and high prices. The variation in temperatures and the variation in energy prices each have about the same impact on levels of fuel poverty.

Fuel poverty is lower with high efficiency and high prices than with low efficiency and low prices. It is also lower with high efficiency and medium prices than with medium efficiency and low prices, but lower with low efficiency and medium prices than medium efficiency and high prices. The variation in efficiency has more impact on the levels of fuel poverty than the variation in prices.

The most interesting relationship has been kept for last. Energy consumption, carbon emissions and fuel poverty are all significantly lower with cooling and high efficiency than with high warming and low efficiency and about the same as with moderate warming and medium efficiency. Moderate warming and medium efficiency leads to slightly higher emissions but slightly lower energy expenditure and fuel poverty than the high warming and low efficiency scenario (this difference is because of the different relative effects on gas and electricity consumption). The range in energy efficiency has a greater impact on both emissions and fuel poverty than the range in temperatures. To emphasise, emissions and fuel poverty would be about the same if England cooled by 2°C and the maximum efficiency scenario had been followed as emissions and fuel poverty would be if England warmed by 4°C and the medium efficiency scenario had been followed.

The answer to the threat of collapse of the THC and cooling leading to increased carbon emissions and increased fuel poverty is clear. It is to make additional improvements to household energy efficiency. The only other approach to tackle fuel poverty (since the climate and world energy prices are not in any significant way under the influence of British government policy) would be significant redistribution. However, the scale of the redistribution required would be very substantial…

An obvious objection to the idea of improving household energy efficiency to compensate for cooling is that although it would be fairly easy to follow the medium efficiency scenario rather than the minimum efficiency scenario, the maximum efficiency scenario is impractical because it requires insulating all the solid-walled homes. Internal wall insulation would be too disruptive and external wall insulation would be denounced as architectural vandalism by the heritage lobby.

Another objection that could be made is that insulating solid walls is just not cost effective. But what is the impact of the different temperature and energy price scenarios on the cost-effectiveness of energy efficiency measures? For that matter, would some measures that are currently cost effective stop being cost effective if there was rapid warming?

The effect on heating costs of the three different temperature and the three different energy price scenarios is shown below. Because both prices and the changes in the prices of gas and electricity are so different, they are shown separately.

As already stated, the price of gas to domestic customers rises by 2% from the level of 2000 in the low price scenario, by 20% in the medium price scenario and by 61% in the high price scenario. The price of off-peak electric heating to domestic customers rises by 65% in the low price scenario, by 77% in the medium price scenario and by 106% in the high price scenario.

The effect on heating demand of the three different temperature scenarios can be calculated from examining different model runs. The effect on space heating demand (in the low efficiency scenario, which is not confused by the different amounts of dCHP viable at different temperatures as the maximum efficiency scenario and the medium efficiency scenario are) is that in the cooling scenario space heating demand increases by 30%, in the moderate warming scenario space heating demand decreases by 15% and in the rapid warming scenario space heating demand decreases by 45%.

Table 7 Relative gas heating costs in the different scenarios (2000 level=1)

	Cooling	Moderate warming	High warming
High energy prices	2.09	1.37	0.89
Medium energy prices	1.56	1.02	0.66
Low energy prices	1.33	0.87	0.56

Table 8 Relative off-peak electric heating costs in the different scenarios (2000 level=1)

	Cooling	Moderate warming	High warming
High energy prices	2.68	1.75	1.13
Medium energy prices	2.30	1.50	0.97
Low energy prices	2.15	1.40	0.91

The current costs and annual savings from different energy efficiency measures are based on calculations by the Buildings Research Establishment using the BREDEM model and a table provided by EST. Payback times have been calculated by the authors. In the table below, the gas figure is for an average-sized home with a 90% efficient A-rated condensing boiler and the electric figure is for an average-sized home with electric storage heating

Table 9 Current costs and annual savings times of energy efficiency measures with a 90% efficient gas boiler or electric storage heating

Insulation measure	Cost (£)	Life of measure	£/year saving (gas)	Carbon saving kgC/yr (gas)	Payback years (gas)	£/year saving (electric)	Carbon saving kgC/yr (electric)	Payback years (electric)
External wall insulation(u=0.35)	3500-5500 (1500 marginal over maintenance)	Not known	115	460	30-48 (13 if needs work anyway)	210	1110	17-26 (7 if needs work anyway)
Internal wall insulation (u=0.35)	1200	Life of building	115	460	10	210	1110	6
Internal wall insulation (u=0.45)	1000	Life of building	110	440	9	200	1060	5
Cavity wall insulation	500	Life of building	65	265	7.5	115	640	4.5
Single to low-e double glazing	2400-4000	15-20	30	120	80-130	55	290	45-70 years
Secondary glazing (u-value=3.0)		15	20	85		70	195	
Draught-stripping windows and doors	210	15	5	25	40	10	65	20
Hot water tank insulation	20	Life of tank	25	95	1	45	150	0.5
Loft insulation 250mm in empty roof	325	Life of building	70	270	4.5	125	690	2.5
Loft insulation top-up to 250mm from 100mm	265	Life of building	10	45	25	20	105	13
Solar water heating	2500-4000 (1500 bulk)		25	90	100-160 (60 bulk)	45	175	55-100 (33 bulk)

The figures for internal wall insulation are based on the assumption that it is carried out when the home is being refurbished anyway. Internal wall insulation requires removing radiators before it is installed and then refitting them afterwards. It also requires redecorating at least the external wall or walls of the room – in practice, redecoration of the entire room is the most practical option. If refurbishment is not taking place at the same time, costs are much higher, perhaps double those quoted, although they may still be lower than for external wall insulation.

A rate of return of 6% is equivalent to a payback period of 12 years. This is about the rate of interest on a mortgage. However, private discount rates for energy efficiency are often much higher and require faster payback times. Householders often demand a payback time of four years, equivalent to a rate of return of 19%. It can be seen that at present energy prices, the only measure that most gas-heated homes do not have which is cost-effective using a 6% discount rate for a home with a 90% efficient condensing boiler of return is cavity wall insulation. For solid-walled homes, internal insulation is cost effective if the home is being refurbished anyway and external wall insulation is nearly cost-effective if maintenance work is needed anyway. They are a long way from being cost-effective on their own. Even upgrading loft insulation from 100mm to 250mm is not cost-effective, but although loft insulation is listed as having a lifetime equivalent to the life of the building, other sources state that loft insulation is only effective for 30 years. The loft insulation installed in the 1970s is now nearing the end of its effective life and its replacement is clearly cost-effective. Double glazing and solar water heating are a very long way from being cost-effective. However, double glazing is cost effective even in gas-heated homes with a 90% efficient condensing boiler when windows need replacing anyway and is now required by building regulations for replacement windows.

The Treasury discount rate is now 3.5% (HM Treasury 2003) and the Government takes the social cost of carbon emissions to be £70 per tonne of carbon in 2000, rising by £1 per tonne of carbon each subsequent year (Clarkson and Deyes 2002). Under those assumptions, external wall insulation becomes cost-effective if maintenance is needed anyway and upgrading loft insulation also becomes cost-effective, but solid-wall insulation on its own still does not become cost-effective. Double glazing and solar water heating remain a long way from being cost-effective.

The effect of the different climate and energy price scenarios alter what is cost-effective at a 6% discount rate for a home with a 90% efficient condensing boiler (by 2030 there will be almost no boilers still operating that are not condensing boilers), but most measures are unaffected because they are either extremely cost-effective (hot water tank insulation and having some loft insulation) or a very long way from being cost-effective (solar water heating, double glazing, draught-proofing, external wall insulation unless work is needed anyway). Among the scenarios with higher heating costs (the three cooling scenarios and two of the three moderate warming scenarios) all except the moderate warming and medium energy prices scenario bring into cost-effectiveness external wall insulation if work is needed anyway. At the extreme, cooling and high energy prices raise the cost of gas heating by a factor of 2.09. It is the only scenario that makes internal wall insulation cost-effective with a 6% discount rate in most cases where refurbishment is not necessary anyway. It also brings upgrading loft insulation from 100mm to 250mm to a payback time of 12 years, on the border of being cost effective with a 6% discount rate. With the scenarios which lower the cost of heating (the three rapid warming scenarios and one of the moderate warming scenarios), external wall insulation if work is needed anyway is pushed further away from being cost-effective with a 6% discount rate and both high warming with low energy prices and high warming with medium energy prices push internal wall insulation out of cost-effectiveness with a 6% discount rate even if the home is being refurbished anyway. With high warming and low energy prices, cavity wall insulation has a payback time of 11 years, making it only just cost-effective with a 6% discount rate. It should be borne in mind, though, that cavity wall insulation is used in countries that are already much warmer than Britain, such as Australia, not only to keep warm in low temperatures but also to keep cool in high temperatures.

For a discount rate of 3.5% and the social cost of carbon emissions £70 per tonne of carbon in 2000, rising by £1 per tonne of carbon each subsequent year, the social cost of carbon in 2030 is £100 per tonne. In the scenarios with higher costs (the three cooling scenarios and two of the three moderate warming scenarios) all except the moderate warming and medium energy prices scenario bring solid wall insulation on its own into cost-effectiveness. Double glazing and solar water heating remain far from being cost effective. In the scenarios with lower heating costs, external insulation if work is needed anyway remains cost-effective, but topping up loft insulation from 75mm to 250mm stops being cost effective.

For homes with off-peak electric storage heating, cavity wall insulation, internal insulation if the home is being refurbished anyway and external wall insulation if maintenance work is needed anyway are all easily cost effective with a 6% discount rate at present temperatures and prices. Internal wall insulation will be cost-effective with a 6% discount rate in many cases where refurbishment is not necessary, depending very much on the cost of redecoration. Upgrading loft insulation is nearly cost-effective with a 6% discount rate even if it is not nearing the end of its effective life. Double glazing and solar water heating remain a very long way from being cost-effective.

With a 3.5% discount rate and the social cost of carbon emissions £70 per tonne of carbon in 2000, rising by £1 per tonne of carbon each subsequent year, upgrading loft insulation is cost-effective, both internal and external solid wall insulation are cost-effective in their own right, but double glazing and solar water heating remain not cost-effective.

What is the impact of changes in temperatures and energy prices in the different scenarios for the cost-effectiveness of measures in homes which have electric storage heating? Only two of the scenarios (high warming with low energy costs and high warming with medium energy costs) see a reduction in heating costs and it is small, making no significant difference to the cost-effectiveness of measures. In the high warming with high energy costs scenario, heating costs increase 13%, bringing upgrading loft insulation from 100mm to 250mm into cost-effectiveness and making internal wall insulation cost-effective with a 6% discount rate in some more cases. Moderate warming with low energy prices increases heating costs by 40%, just bringing the cheapest external wall insulation into cost-effectiveness with a 6% discount rate even if other work is not needed externally. Moderate warming with medium energy prices increases heating costs by 50% above recent levels and brings only more cases of external and internal wall insulation into cost-effectiveness with a 6% discount rate. Moderate warming with high energy prices increases heating costs by 75% above recent levels and brings draught-proofing into cost-effectiveness with a 6% discount rate, although it is not an important measure, as well as more cases of external wall insulation and internal wall insulation that requires redecoration. Cooling with low energy prices increases heating costs 115% above recent levels and brings external wall insulation into cost-effectiveness in all cases with a 6% discount rate and more cases of internal wall insulation that requires redecoration. Cooling with medium energy prices increases heating costs 130% above recent levels and brings yet more cases of internal wall insulation that requires redecoration into cost-effectiveness with a 6% discount rate. Cooling with high energy prices increases heating costs 168% above recent levels and brings more cases of internal wall insulation that requires redecoration into cost effectiveness with a 6% discount rate and nearly brings bulk installation of solar water heating into cost-effectiveness.

With a 3.5% discount rate and the social cost of carbon emissions £100 per tonne of carbon in 2030, rising by £1 per tonne of carbon each subsequent year, double glazing may be cost-effective in the cooling scenarios, depending on how expensive it is, bulk solar water heating is cost-effective in the moderate warming and the cooling scenarios, and individual solar water heating edges into cost-effectiveness in the cooling and high energy price scenario.

Next, consider the impact of the changes in temperatures and energy prices in the different scenarios on standard rate electric heating. In the scenarios, it is assumed that this kind of heating, which is extremely expensive, will not be used by 2030 in the form of conventional electric resistance heating. However, in the maximum efficiency scenario it is assumed that all electric heating has moved over to heat pumps on standard rate electricity and in the medium efficiency scenario that 10% of electrically heated homes have done so, although 90% are on electric storage heating.

In the low energy price scenario, the cost of standard rate electricity is assumed to rise by 30% by 2030, in the medium energy price scenario it rises by 35% and in the high energy price scenario it rises by 49% Again, in the cooling scenario space heating demand increases by 30%, in the moderate warming scenario space heating demand decreases by 15% and in the rapid warming scenario space heating demand decreases by 45%.

Table 10 Relative standard rate electric heating costs in the different scenarios (2000 level=1)

	Cooling	Moderate warming	High warming
High energy prices	1.94	1.27	0.82
Medium energy prices	1.75	1.15	0.74
Low energy prices	1.69	1.10	0.71

The table below shows the results for conventional electric heating with standard rate electricity and the authors' calculation for the results with 350% efficient heat pumps at present energy prices. It should of course be borne in mind that heat pumps currently cost a few thousand pounds, but unlike other measures, it is reasonable to expect the cost to fall dramatically by 2030.

Table 11 Current costs and annual savings times of energy efficiency measure with standard rate electricity

Insulation measure	Cost (£)	Life of measure	Carbon saving kgC/yr (resistance)	£/year saving (resistance)	Payback years (resistance)	Carbon saving kgC/yr (heat pump)	£/year saving (heat pump)	Payback years (heat pump)
External wall insulation(u=0.35)	3500-5500 (1500 marginal over maintenance)	Not known	1110	490	7-11 (3 if needs work anyway)	315	140	25-40 (11 if needs work anyway)
Internal wall insulation (u=0.35)	1200	Life of building	1110	490	2.5	315	140	8
Internal wall insulation (u=0.45)	1000	Life of building	1060	465	2	305	130	8
Cavity wall insulation	500	Life of building	640	285	2	185	80	6
Single to low-e double glazing	2400-4000	15-20	290	125	19-32 years	85	35	70-115 years
Secondary glazing (u-value=3.0)		15	195	70		55	20	
Draught-stripping windows and doors	210	15	65	30	7	20	10	20
Hot water tank insulation	20	Life of tank	150	120	2 months	45	35	0.5
Loft insulation 250mm in empty roof	325	Life of building	690	270	1	195	75	4.5
Loft insulation top-up to 250mm from 100mm	265	Life of building	105	45	6	30	15	18
Solar water heating	2500-4000 (1500 bulk)		175	110	23-37 (14 bulk)	50	30	80-130 (50 bulk)

For electrically heated homes on standard rate electricity, all measures are already cost-effective with a 6% discount rate except double glazing and solar water heating. With a 3.5% discount rate and a social cost of carbon of £70 per tonne in 2000, rising by £1 per tonne per year, double glazing and solar water heating are also cost-effective. It is assumed in the scenarios that conventional resistance heating on standard rate electricity will not be used by 2030.

At present electricity prices, savings and payback times for a home with a heat pump are similar to those with a 90% efficient condensing gas boiler. Hot water tank insulation, loft insulation in an empty roof and cavity wall insulation are all definitely cost-effective with a 6% discount rate. Internal wall insulation is cost-effective with a 6% discount rate if the house needs refurbishment anyway. External wall insulation is just cost-effective with a 6% discount rate (payback 11 years) if work is needed anyway. The other measures are not cost-effective with a 6% discount rate.

With a 3.5% discount rate and a social cost of carbon of £70 per tonne in 2000, rising by £1 per tonne per annum, topping up loft insulation, draught-proofing and both internal and external solid wall insulation are cost-effective, but double glazing and solar water heating are far from being cost-effective.

Looking to the future, in all the high warming scenarios, heating costs decrease and external wall insulation ceases to be cost-effective with a 6% discount rate even if work is needed anyway, but the other measures that are presently cost-effective remain cost-effective. In the moderate warming scenarios, heating costs rise slightly, so external wall insulation becomes more definitely cost-effective with a 6% discount rate if work is needed anyway. In the cooling scenarios, heating costs nearly double and so internal wall insulation becomes cost-effective with a 6% discount rate in many cases even where refurbishment is not necessary anyway. In addition, increasing loft insulation from 100mm to 250mm becomes cost-effective with a 6% discount rate even if the existing insulation is not nearing the end of its life.

With a 3.5% discount rate and a social cost of carbon of £100 per tonne in 2030, rising by £1 per tonne per year, external solid wall insulation is not cost-effective on its own in the high warming scenarios, although it is cost-effective if work is needed anyway. The other measures that are cost-effective under present circumstances remain cost-effective. In the moderate warming and the cooling scenarios, there is no change from present - topping up loft insulation, draught-proofing and both internal and external solid wall insulation are cost-effective, but double glazing and solar water heating are far from being cost-effective.

Since heating an average-sized home with filled cavity walls and an insulated loft, but electric storage heating costs about £350 a year now, which could be reduced by about £125 a year by switching to a heat pump on standard rate electricity, a heat pump would have to cost less than £1500 to be cost-effective at a 6% discount rate or about £3000 with a discount rate of 3.5% and a social cost of carbon of £75 per tonne, rising at £1 per tonne per year. With electric heating costs increasing substantially in all the scenarios except those with rapid warming, it can be seen that switching to a heat pump may be cost-effective even in that situation by 2030. Heating an average-sized home with solid walls and an insulated loft, electric storage heating costs about £500 a year now, which would be reduced by nearly £200 a year by switching to a heat pump on standard rate electricity. A heat pump would have to cost less than about £2500 to be cost-effective at a 6% discount rate or about £5000 with a discount rate of 3.5% and a social cost of carbon of £75 per tonne, rising at £1 per tonne per year.

The biggest problems with internal and external wall insulation are not really about their cost-effectiveness. External wall insulation suffers from the disadvantages of its high capital cost, the need to get planning permission to fit it and that many people regard it as unattractive. Internal wall insulation is already cost-effective for many electrically-heated homes, but the inconvenience of installing it means that it is almost never done except in vacant homes that need refurbishment anyway.

The technology which has not been considered so far in this section is micro-CHP. It is much more difficult to talk in general about the savings from micro-CHP because they depend so much on the heat demand of the building. Stirling engine micro-CHP technology has to be of a certain size and heat demand to be efficient. Savings are therefore not easily scaled as they can be for other measures – there needs to be a significant heat demand for space heating and hot water to make one preferable to a condensing gas boiler. The threshold is a total thermal demand (space heating and hot water) of about 12,000 kWh per annum.

But it is possible to go back and adjust the results from the ECI simulation. In the medium efficiency scenarios 90% of gas-heated homes have 92% efficient condensing gas boilers while only 10% of gas-heated homes with sufficient heat demand have micro-CHP. What if we increase the proportion of such homes with micro-CHP to 95%? What happens to carbon emissions and fuel poverty in that case?

Table 12 shows the results. Comparing this table with the results for the medium efficiency scenarios in Tables 4 to 6, it can be seen that carbon emissions are only about 3 to 4% than in those scenarios, whereas in the high efficiency scenarios they were about 15% less than the medium efficiency scenarios with high warming, about 30% less with cooling and halfway between those with moderate warming. When the results for fuel poverty levels are compared, though, the levels of fuel poverty are almost as low as in the maximum efficiency scenario. So just adding micro-CHP can do almost as much for fuel poverty as making all possible energy efficiency improvements, including micro-CHP. The reason for this is that when all efficiency improvements are made a smaller proportion of homes have a combined thermal demand above 12,000 kWh a year (particularly among solid-wall homes), so a smaller number of properties can effectively use micro-CHP. The financial savings on the electricity bill from micro-CHP are almost as great as the financial savings on the heating bill from maximum insulation.

Another way to reduce bills and carbon emissions is to install heat pumps in homes that are electrically heated. Gas heating would be cheaper to run, but the carbon emissions are higher. The carbon emissions of a kilowatt-hour of heat from gas are 0.19kg. With a 90% efficient gas boiler they are 0.21kg. The carbon dioxide emissions from a kilowatt-hour of electricity now are about 0.43kg, but according to DTI (2003c) predictions by 2030 they will be only 0.24kg (85% of electricity from 68% efficient combined cycle gas turbines and the rest from carbon-free sources). A kilowatt-hour of heat from a 350% efficient heat pump would only emit 0.07kg of carbon dioxide – a third of the emissions from a 90% efficient gas boiler. The disadvantage is that using a heat pump will be more expensive than using gas.

When the proportion of heat pumps in electrically heated homes is raised to 95% in addition to the 95% of suitable gas-heated homes, fuel poverty falls a bit further, to about the same level as in the maximum efficiency scenarios, but carbon dioxide emissions fall only a small amount and remain well above the levels in the maximum efficiency scenarios.

It might be possible to instead extend the coverage of the gas network to virtually all homes. The running cost of gas heating is expected to be slightly cheaper than heat pumps in 2030, so fuel poverty would be marginally lower than shown in Table 13, but because the carbon emission of gas heating will be only slightly lower than those of conventional electric heating in 2030, emissions would be about the same as shown in Table 12.

The heavy reliance on gas that is assumed to continue until 2030 makes sense in terms of reducing fuel poverty, but less sense in terms of minimising carbon emissions. Heat pumps are the way to do that. As renewables and carbon capture will be developed during the course of the century to reduce emissions and gas will become increasingly scarce and expensive, a long-term transition to heat pumps as the predominant method of heating should be planned.

Table 12: Medium Efficiency Scenarios with 95% rather than 10% dCHP

	Temperature	Growth/ Distribution	Energy price	CO_2 emissions (million tonnes)	% change emissions since 1990	£ Billion domestic energy	Fuel poor households	% fuel poor households
1	High	High	High	77.15	-38.3%	18.45	50,000	0.2
2	High	High	Medium	77.15	-38.3%	15.56	<25,000	<0.1
3	High	High	Low	77.15	-38.3%	14.30	<25,000	<0.1
4	High	Medium	High	74.75	-40.2	17.65	550,000	2.3
5	High	Medium	Medium	74.75	-40.2	14.85	300,000	1.2
6	High	Medium	Low	74.75	-40.2	13.63	225,000	0.9
7	High	Low	High	70.81	-43.4	16.60	1,250,000	5.6
8	High	Low	Medium	70.81	-43.4	13.95	900,000	4.1
9	High	Low	Low	70.81	-43.4	12.80	800,000	3.6
10	Moderate	High	High	94.27	-24.6	20.47	125,000	0.5
11	Moderate	High	Medium	94.27	-24.6	16.94	50,000	0.2
12	Moderate	High	Low	94.27	-24.6	15.40	<25,000	<0.1
13	Moderate	Medium	High	91.94	-26.4	19.64	750,000	3.3
14	Moderate	Medium	Medium	91.94	-26.4	16.21	400,000	1.7
15	Moderate	Medium	Low	91.94	-26.4	14.70	275,000	1.3
16	Moderate	Low	High	87.30	-30.2	18.54	1,525,000	6.8
17	Moderate	Low	Medium	87.30	-30.2	15.28	1,100,000	4.9
18	Moderate	Low	Low	87.30	-30.2	13.85	925,000	4.1
19	Cooling	High	High	119.74	-4.2	23.52	325,000	1.3
20	Cooling	High	Medium	119.74	-4.2	19.04	100,000	0.4
21	Cooling	High	Low	119.74	-4.2	17.08	50,000	0.2
22	Cooling	Medium	High	117.51	-6.0	22.71	1,175,000	5.0
23	Cooling	Medium	Medium	117.51	-6.0	18.32	625,000	2.7
24	Cooling	Medium	Low	117.51	-6.0	16.40	425,000	1.8
25	Cooling	Low	High	111.68	-10.7	21.44	2,050,000	9.2
26	Cooling	Low	Medium	111.68	-10.7	17.26	1,350,000	6.0
27	Cooling	Low	Low	111.68	-10.7	15.44	1,100,000	4.9

Figure 7: CO_2 emissions (million tonnes) in medium efficiency scenarios with 95% rather than 10% micro-CHP

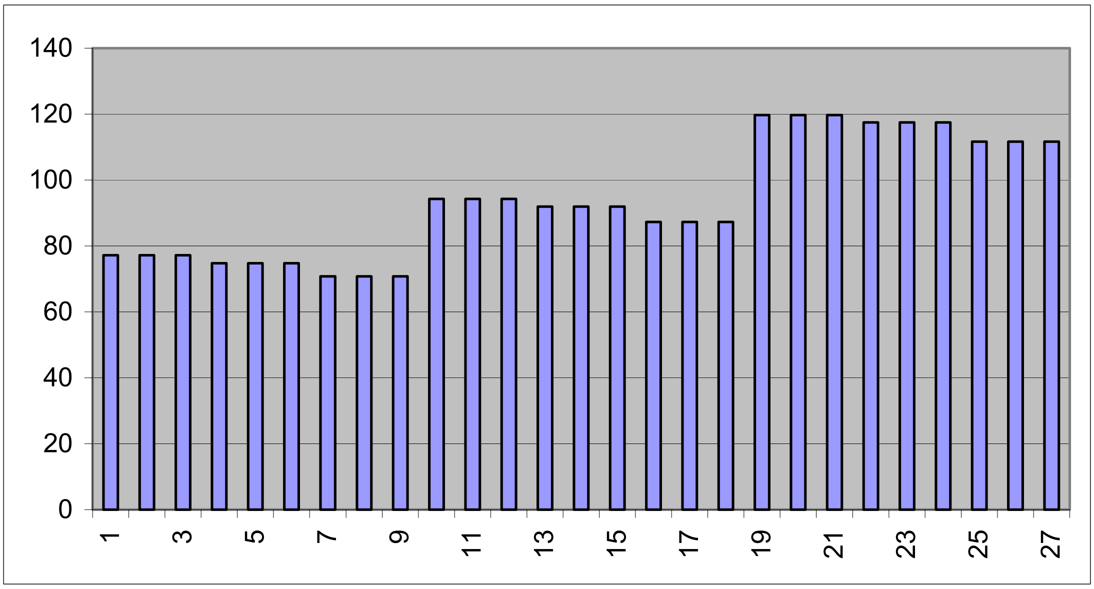


Figure 8: Percentage of fuel poor households in medium efficiency scenarios with 95% rather than 10% micro-CHP

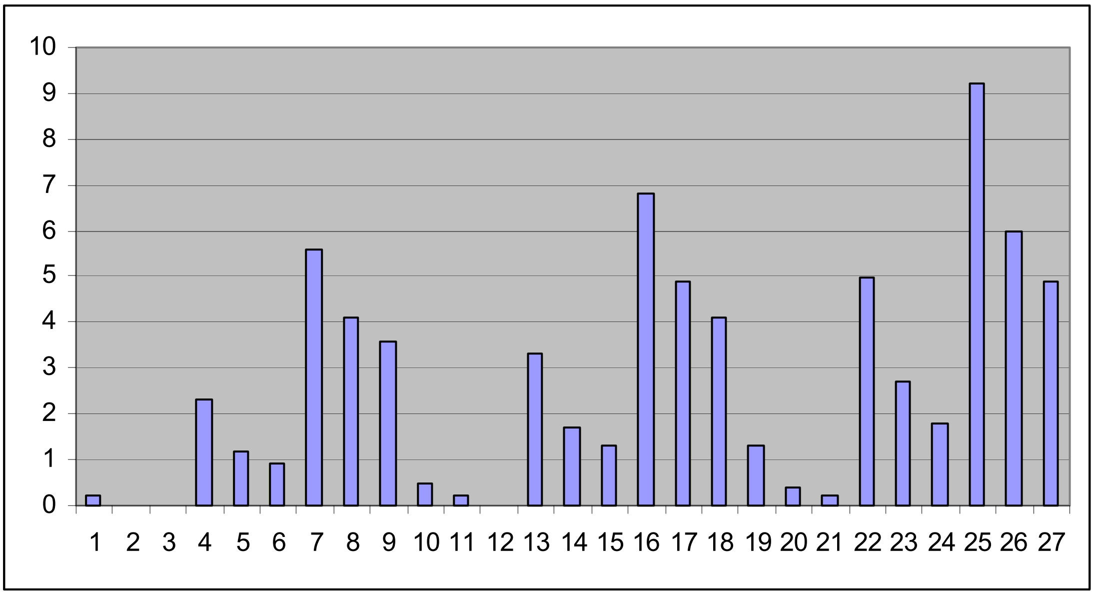


Table 13: Medium Efficiency Scenarios with 95% rather than 10% micro-CHP and 95% rather than 10% heat pumps

	Temperature	Growth/ Distribution	Energy price	CO2 emissions (million tonnes)	% change emissions since 1990	£ Billion domestic energy	Fuel poor households	% fuel poor households
1	High	High	High	73.99	-40.8%	17.75	50,000	0.2
2	High	High	Medium	73.99	-40.8%	14.99	<25,000	<0.1
3	High	High	Low	73.99	-40.8%	13.78	<25,000	<0.1
4	High	Medium	High	71.67	-42.3	16.96	450,000	1.8
5	High	Medium	Medium	71.67	-42.3	14.29	250,000	1.1
6	High	Medium	Low	71.67	-42.3	13.12	175,000	0.8
7	High	Low	High	67.87	-45.7	15.95	1,150,000	5.2
8	High	Low	Medium	67.87	-45.7	13.41	825,000	3.7
9	High	Low	Low	67.87	-45.7	12.31	725,000	3.2
10	Moderate	High	High	90.11	-27.9	19.55	100,000	0.4
11	Moderate	High	Medium	90.11	-27.9	16.18	25,000	0.1
12	Moderate	High	Low	90.11	-27.9	14.71	<25,000	<0.1
13	Moderate	Medium	High	87.85	-29.7	18.73	650,000	2.7
14	Moderate	Medium	Medium	87.85	-29.7	15.45	325,000	1.4
15	Moderate	Medium	Low	87.85	-29.7	14.02	225,000	1.0
16	Moderate	Low	High	83.39	-33.3	17.67	1,400,000	6.3
17	Moderate	Low	Medium	83.39	-33.3	14.56	925,000	4.1
18	Moderate	Low	Low	83.39	-33.3	13.20	775,000	3.5
19	Cooling	High	High	114.05	-8.8	22.25	250,000	1.0
20	Cooling	High	Medium	114.05	-8.8	18.00	75,000	0.3
21	Cooling	High	Low	114.05	-8.8	16.14	50,000	0.2
22	Cooling	Medium	High	111.87	-10.5	21.46	1,000,000	4.1
23	Cooling	Medium	Medium	111.87	-10.5	17.29	500,000	2.0
24	Cooling	Medium	Low	111.87	-10.5	15.46	325,000	1.4
25	Cooling	Low	High	106.30	-15.0	20.24	1,775,000	8.0
26	Cooling	Low	Medium	106.30	-15.0	16.28	1,150,000	5.2
27	Cooling	Low	Low	106.30	-15.0	14.55	950,000	4.3

Figure 9: CO_2 emissions (million tonnes) in medium efficiency scenarios with 95% rather than 10% micro-CHP and 95% rather than 10% heat pumps

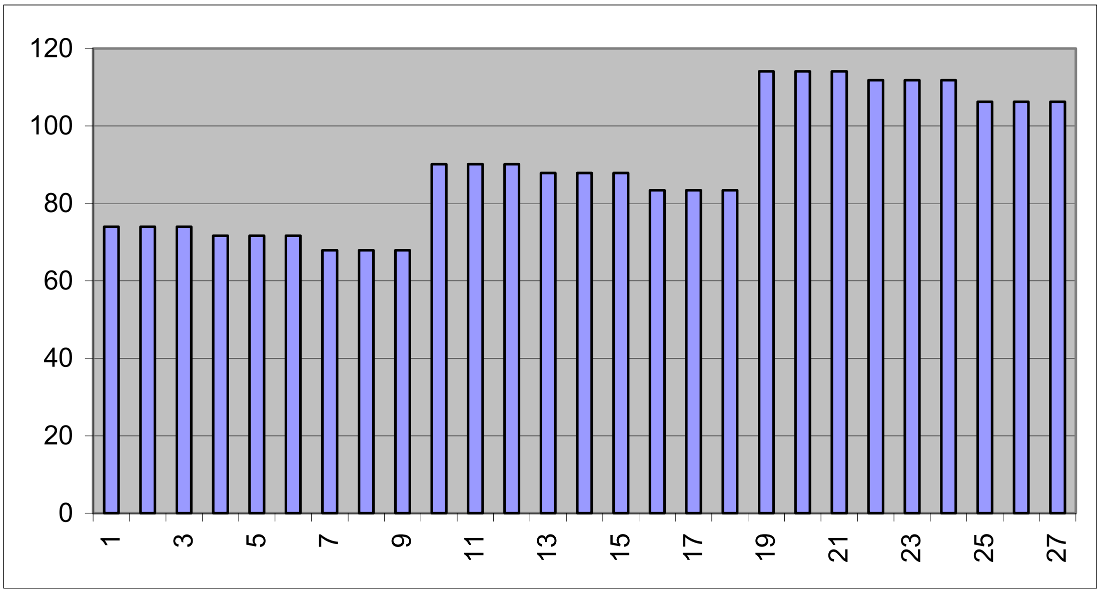
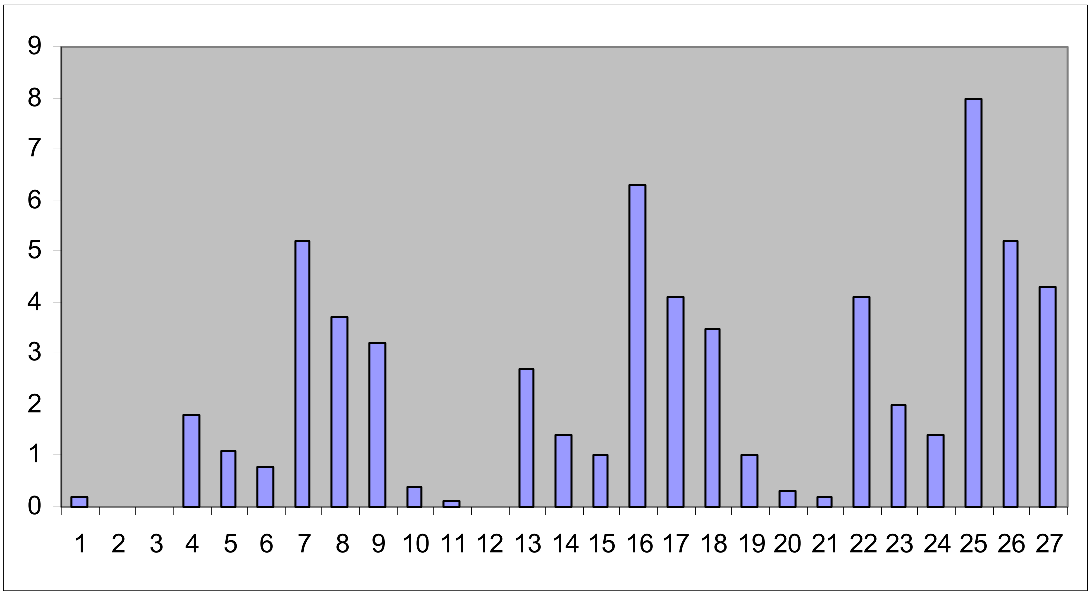


Figure 8: Percentage of fuel poor households in medium efficiency scenarios with 95% rather than 10% micro-CHP and 95% rather than 10% heat pumps



Discussion

A number of interesting findings emerge from the research:

1. In the most likely scenarios, fuel poverty will be reduced substantially, but fall far short of being abolished in 2030.

2. The range of variation in energy efficiency between the scenarios has more impact than the range of temperatures on emissions and fuel poverty levels, so improving energy efficiency can compensate for lower temperatures.

3. The interim 40% reduction target by 2030 is easily achieved in high warming scenarios with high efficiency and nearly achieved with medium efficiency, but only achieved in moderate warming scenarios with high efficiency, and is nearly achieved in cooling scenarios with high efficiency.

4. Fuel poverty is only effectively abolished in scenarios with Scandinavian-style redistribution and remains substantial even with high efficiency and warming if the incomes of the poor rise little due to unequal growth.

5. Expected rising electricity prices worsen fuel poverty and account for some of the difficulty in achieving the target of abolition.

6. However, the dramatic reduction in the carbon intensity of electricity production reduces total household carbon dioxide emissions by about 20% compared to what it would be if the carbon intensity of electricity remained similar to what it is today.

7. Micro-CHP can play almost as substantial a role in reducing fuel poverty as insulating solid walls, although it does not reduce carbon emissions anything like as much.

Two fundamental conclusions can be reached about carbon emissions and about fuel poverty.

In the high warming scenarios, medium efficiency measures bring carbon emissions down by around the interim target of 40% compared to 1990 levels, but the only way for households in the moderate warming scenarios to reduce their carbon emissions by 40% by 2030 is with the maximum efficiency measures - including the insulation of solid walls. The maximum efficiency measures even bring the 40% target close to being met in the cooling scenarios. The variant of the medium efficiency scenarios with 95% uptake of micro-CHP is only slightly better than the standard medium efficiency scenario in terms of carbon emissions, so there is no easy alternative to the insulation of solid walls if the domestic sector is to play its part in meeting carbon emissions reduction targets. The only other way to achieve the objective would be by demolishing solid-wall homes and building new ones, which would be much more expensive and even more controversial.

The only way by 2030 to achieve the Government's target for the abolition of fuel poverty is with income redistribution as well as greater energy efficiency. This is the case even in the high warming scenarios. Improving energy efficiency alone cannot resolve fuel poverty because some households have very low incomes. This finding has important implications. Behind the problem of fuel poverty lies a deeper problem of simple income poverty. The energy efficiency of the existing housing stock cannot be increased sufficiently for it to resolve the issue on its own.

What kind of policies are required to bring about the necessary changes? If the domestic sector is to play its part in bringing about the interim carbon reduction target of 40% by 2030, an aggressive programme to insulate solid walls as well as cavity walls would be needed, despite the cost, inconvenience and controversy that it would entail. If reducing carbon emissions was the only concern, then the replacement of conventional gas and electric heating technologies with heat pumps could substitute for solid wall insulation, although running costs for consumers would be higher than with efficient gas boilers.

If fuel poverty is to be eliminated without concern about reducing carbon emissions, extensive solid wall insulation is not necessarily required because micro-CHP can do almost as much as solid wall insulation to reduce bills. But there would be a need for large-scale income redistribution. If it was to be done through tax credits, as modelled in this project, it would require substantial increase in tax on the better off. In Scandinavia, there are much higher rates of tax than in the UK, but redistribution is more indirect, through more generous benefits, a more extensive state sector and the state acting as employer of last resort in what are effectively workfare schemes rather like the New Deal in the UK, but with higher rates of pay and applying to larger proportion of those who would otherwise be unemployed.

The implausibility of either policy in the present political climate shows the gap between the future objectives the government has set for fuel poverty and carbon emissions and the measures that are necessary to bring them about.

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