Department of Energy & Climate Change

Fuel Poverty: a Framework for Future Action – Analytical Annex

July 2013

Contents

Section One: Introduction

This analytical annex sets out the details of the analysis that has been undertaken to support the development of the strategic framework for fuel poverty.[1]

Following this Introduction, Section Two presents some high level snap-shots of the group of fuel poor households in 2010. We show statistics on the current extent and depth of fuel poverty under the Low Income High Costs indicator as well as on the composition of this group of households across different demographic, dwelling and socio-economic characteristics.

In Section Three, we present the results of regression analysis that we have undertaken in order to determine the household characteristics that are important in driving a household to be fuel poor or in severe fuel poverty. As we set out in *Fuel Poverty: A Framework for Future Action*, it is important that we have a good understanding of the particular factors that increase the likelihood of a household being fuel poor. This helps us understand how effectively our current package of policies support the fuel poor. It also has the potential to help us design future policies that are better targeted at the households most in need of support.

Section Four sets out the methodology, assumptions and results of our work on fuel poverty projections. These projections are important in allowing us to understand the scope to make further progress to reduce fuel poverty through policy interventions.

Section Five sets out the work to construct the Fuel Poverty Marginal Alleviation Cost Curve (FP-MACC). This work builds on the fuel poverty projections set out in Section Four to set out the 'merit order' of fuel poverty interventions. The FP-MACC will be an important tool in shaping future policies as it will help to show where there is cost-effective potential to make progress against the problem and the trade-offs associated with delivering more costly measures.

In Section Six, we set out the results of research that we have undertaken to help to estimate and monetise the health impacts of living in cold and poorly-insulated homes. While this is still a work-in-progress, it represents a big step forward in our understanding of the health impacts of cold homes and offers the possibility of being able to more fully capture the benefits associated with fuel poverty policies.

Finally, Section Seven briefly sets out our proposal for the efficiency standard that we would propose to use as the basis for the fuel poverty target.

[1] See: https://www.gov.uk/government/publications/fuel-poverty-a-framework-for-future-action

Section Two: Fuel poverty statistics

This section presents statistics showing the composition of fuel poor households across different demographic, dwelling and socio-economic characteristics. All of the statistics presented below are based on the 2010 English Housing Survey (EHS) and the LIHC indicator that we have adopted. The most recent fuel poverty statistics – based on the 2011 EHS and which show LIHC figures based on the indicator that was proposed in last year's consultation[2] – were published by the Department of Energy and Climate Change on 16th May 2013.[3]

Table 1: Fuel poverty in England, 2010

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
Fuel poor	2.5	404	1,000
Not fuel poor	19.1	-	-
Total	**21.6**	-	-

[2] The LIHC indicator that was proposed in last year's consultation uses a different set of equivilisation factors to the version of the indicator that we have adopted. That consultation can be found at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66570/6406-fuel-poverty-changing-the-framework-for-measureme.pdf

[3] See: https://www.gov.uk/government/publications/fuel-poverty-report-annual-report-on-statistics-2013

Table 2: Fuel poverty by tenure in England, 2010

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
Owner occupier	1.3	466	618
Private rented	0.7	398	279
Local Authority	0.2	217	51
Registered Social landlord (RSL)	0.2	243	52
Total	**2.5**	**404**	**1,000**

Table 3: Fuel poverty by household composition in England, 2010

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
Couple with dependent children	0.6	448	258
Couple, no dependent children, aged 60 or over	0.4	452	180
Couple, no dependent children, under 60	0.2	389	87
Lone parent with dependent children	0.4	362	131
One person aged 60 or over	0.3	442	133
One person under 60	0.4	298	115
Other multi-person household	0.2	420	95
Total	**2.5**	**404**	**1,000**

Table 4: Fuel poverty by vulnerability in England, 2010[4]

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
Not vulnerable	0.5	354	194
Vulnerable	1.9	418	806
Total	**2.5**	**404**	**1,000**

Table 5: Fuel poverty by income decile group in England, 2010

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
1st decile group (lowest income)	0.9	415	385
2nd income decile group	0.9	372	319
3rd & 4th income decile groups	0.7	429	296
Total	**2.5**	**404**	**1,000**

[4] A vulnerable household is classed as one containing children, someone over 60 years old and/or someone with a long-tern illness/disability.

Table 6: Fuel poverty by dwelling type in England, 2010

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
Converted flat	0.1	261	40
Detached	0.5	661	313
End terrace	0.4	391	154
Mid terrace	0.5	292	140
Purpose-built flat	0.1	221	28
Semi detached	0.9	376	324
Total	**2.5**	**404**	**1,000**

Table 7: Fuel poverty by SAP band (SAP09) in England, 2010

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
B and C	0.0	310	11
D	0.7	209	139
E	1.2	331	410
F	0.4	677	267
G	0.1	1214	173
Total	**2.5**	**404**	**1,000**

Table 8: Fuel poverty by region in England, 2010

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
East England	0.3	430	116
East Midlands	0.3	451	114
London	0.3	331	108
North East	0.2	394	64
North West	0.4	421	160
South East	0.3	416	116
South West	0.3	449	115
West Midlands	0.3	375	113
Yorkshire and Humber	0.2	383	95
Total	**2.5**	**404**	**1,000**

Table 9: Fuel poverty by urban / rural location in England, 2010

Group	Number of households (mn)	Average fuel poverty gap (£)	Aggregate fuel poverty gap (£mn)
Urban	2.0	361	721
Rural	0.5	588	279
Total	**2.5**	**404**	**1,000**

Section three: Modelling the likelihood of being fuel poor

Background

This section examines the impact certain household and dwelling characteristics have on the likelihood of a household being classed as fuel poor (and severely fuel poor) under the LIHC measure.[5] The accompanying document, *Fuel Poverty: A Framework for Future Action* argues that a detailed consideration of the types of characteristics that drive a household to be in fuel poverty is important in understanding which types of households should be prioritised for support through policies.

The analysis presented below is based on the LIHC indicator. Under this measure, a household is considered to be fuel poor if:

1. It has required fuel costs that are above the national median level; and

2. Were the household to spend that amount it would be left with a residual income below the official poverty line (i.e. less than 60 per cent of median income).

The depth of fuel poverty is defined as the amount by which the assessed energy needs of fuel poor households exceed the threshold for reasonable costs. This is referred to as the fuel poverty gap.

The aim of this analysis is to develop a model of the most influential characteristics – that are readily identifiable on the ground – which determine the probability of households being fuel poor/severely fuel poor. The modelling set out in the following sections has been reviewed (and approved) by the Office for National Statistics Methodology Advisory Service.

The model provides an indicative probability of the likelihood that a household is living in fuel poverty based on a set of known characteristics. However, this does not lead to a definitive classification of these households as fuel poor. Rather, it simply indicates a higher probability. Later in this section we examine the number of fuel poor and non-fuel poor households captured using different probability thresholds in the model.

Annex 3A sets out further details of the data used, the methodology applied and the variables considered in the modelling.

[5] For the purpose of this analysis, we classify the one-third of fuel poor households with the highest fuel poverty gaps (in excess of approximately £410) as the group of households in "severe fuel poverty".

Logistic regression modelling

The logistic regression modelling technique assesses how certain characteristics within a household, such as the household reference person's (HRP) employment status or the type of boiler they have in the house, may affect the likelihood of that household being fuel poor.

The advantage of using logistic regression is that it is able to verify whether the patterns commonly seen across fuel poverty are actually associated with single characteristics or a combination of a number of characteristics. For example, we know that:

- More low income households tend to pay for their electricity bills using pre-payment meters, which are generally considered to be the more expensive payment method.

- Households in which the main reference person is unemployed are also more likely to be living in fuel poverty compared to the overall population (36% vs. 11%).

But by holding household characteristics such as the amount of required energy consumption constant and equal, logistic regression helps isolate which of these factors – unemployment or the pre-payment method – has a stronger association with an increase in the odds of being in fuel poverty. The modelled output in the next section shows that *unemployment* is the factor with a greater likelihood of households to be living in fuel poverty.

Table 10 summarises the household and dwelling characteristics considered in the modelling to reliably predict households living in:

i) Fuel poverty under the LIHC indicator; and
ii) Severe fuel poverty - the third of the fuel poor household population with the highest fuel poverty gaps.

Table 10 also details the baseline or 'reference' within each variable and the final set of variables that are retained in each respective model. The reference category is the one with which all other categories are compared. For example, the odds of being fuel poor for all family compositions are compared against couples with no dependent children.

Table 10: Variables considered in the modelling

Variables	Reference category	Low income high costs	Severe fuel poverty
Family Composition	Couple, no dependent child(ren)		
Household size	Number of persons in the household >=5		
Age band of youngest person in household	Aged between 16 to 59		
Individual(s) disabled or with chronic illness	No disabled household members or unknown		
Employment status of household reference person	HRP - Full/Part-time employment		
Employment status (primary) of partner	Partner - Full/Part-time employment		
National Statistics Socio-Economic Classification	Higher managerial and professional occupations		
Household on means tested benefits/tax credits	No		
Attendance allowance or DLA mobility/care	No or No Answer		
Method of payment - electricity	Direct debit		
Method of payment - gas	Direct debit		
Government office region	South East		
Rurality - morphology (COA)	Urban		
Whether dwelling is on the gas network	On gas network		

Variables	Reference category	Low income high costs	Severe fuel poverty
Dwelling type	Flat	■	■
Dwelling age	Post-1964	■	■
Total no of bedrooms	One bedroom		
Useable floor area	Less than 50 sqm	■	■
Tenure	Local Authority/RSL	■	■
Under occupancy	Not under occupying	■	■
Energy efficiency rating band (SAP 2005)	A, B or C		
Loft insulation thickness	150mm or more	■	■
Type of wall and insulation	Cavity with insulation		
Age of heating system	Less than 3 years	■	■
Main heating fuel	Gas	■	■
Main heating system	Central heating		
Water heating system	With central heating		
Type of boiler	All condensing boiler	■	■

■ Included in the final model

The regression model shows the individual effect each characteristic has on the odds of a household being fuel poor, compared to a household with the above baseline set of reference characteristics. Characteristics with an odds ratio greater than 1 imply an increased likelihood of a household with that particular characteristic living in fuel poverty compared to the reference characteristic. Conversely, an odds ratio less than 1 implies a reduced likelihood – holding all other characterises constant and equal. The same principle applies to the effect on the odds of households that are severely fuel poor.

This is graphically shown in Figure 1 and Figure 2, where the bars indicate the proportionate effect on the odds for each category compared with the baseline reference category. An increase in odds (odds ratio > 1) is shown with a right hand bar, and a decrease (odds ratio < 1), with a left hand bar. The confidence intervals for the effects of each category are also shown in the charts – the shorter the length, the more precise the estimate of the associated odds ratio. Where a confidence interval spans the value of 1, this indicates that the effect of the category is not significantly different from the baseline category. It should be noted that the scale of the charts is logarithmic rather than linear.

Modelled output for households living in fuel poverty

Figure 1 shows the final modelled outcome for predicting households that are fuel poor. The model was created by using a backward elimination procedure. In doing so the following variables were dropped from the model as they were not found to be statistically significant (in some cases there was also multicollinearity[6] between the variables): family composition, disability, method of payment for gas, region, rurality, the number of bedrooms in the household and type of space heating and water heating system.

Other variables – such as SAP rating – were deliberately left out of the model. Whilst we would expect SAP rating to be a strong predictor of household energy costs, we know that SAP rating is determined by a number of other dwelling characteristics (e.g. heating type, level of insulation, size of dwelling) and, as such, is not as useful in determining the specific factors that are driving households to be fuel poor.

The size of the effects, the corresponding 95% confidence intervals, Wald statistics and the validation tests for the model can be found in Annex 3B.

The findings from the regression analysis for all LIHC households (Figure 1) are intuitive. Household characteristics associated with higher instances of modelled energy costs and low incomes tend to be the ones that increase the likelihood of being fuel poor.

[6] Multicollinearity occurs when two or more predictor variables in the model are highly *correlated* and so provide redundant additional information about the response variable in the model – in this case, whether or not the household is in fuel poverty.

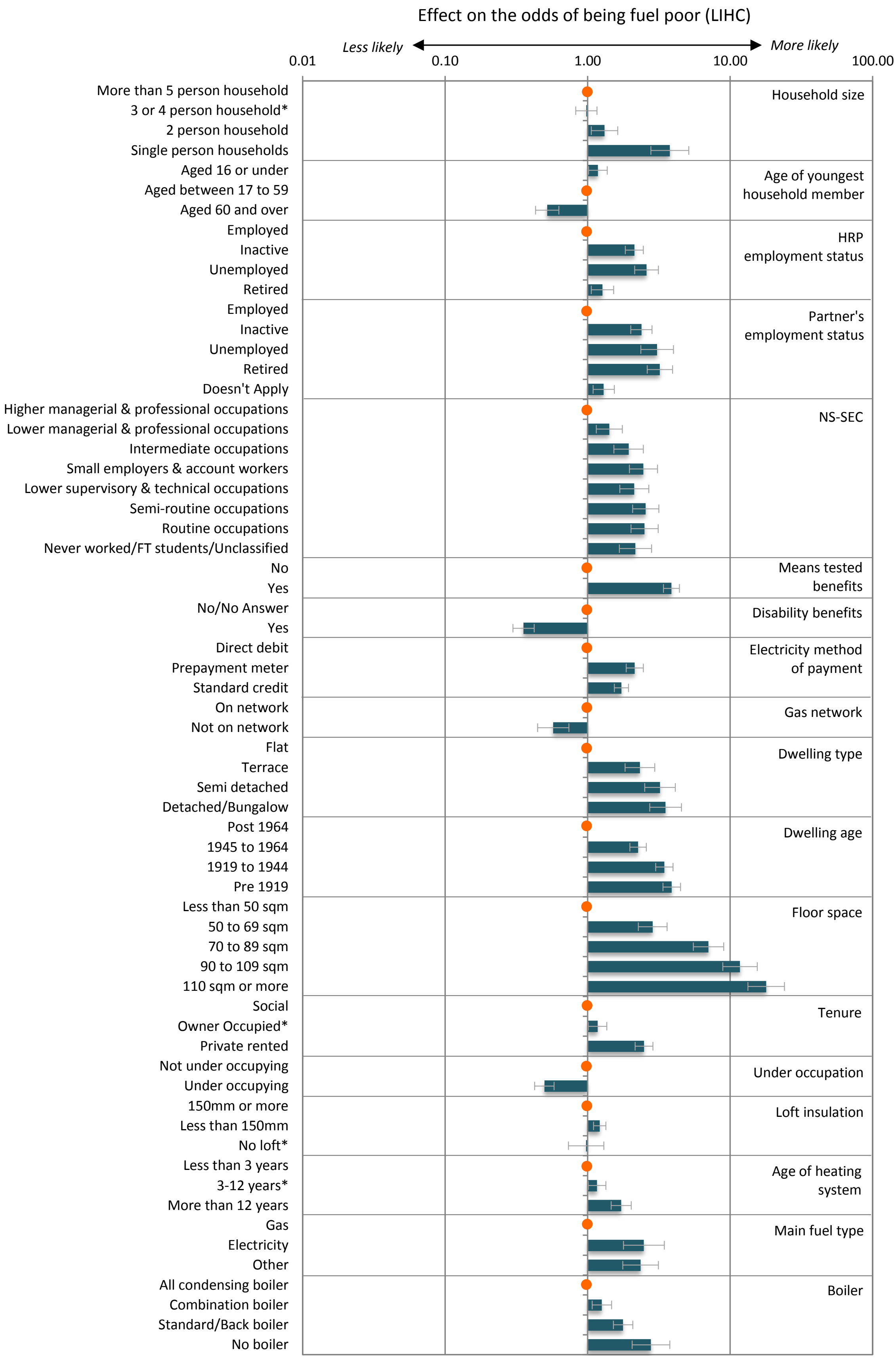
Holding all other characteristics constant and equal, the model shows that against the baseline characteristic for each group:

- Single one person households have higher odds of being fuel poor compared to larger households with more occupants – here the odds are almost four times that of households with five or more occupants.
- Households with children aged below 16 also face significantly higher odds of being fuel poor (almost 20% higher). On the other hand, pension aged households (where the youngest household member is aged 60 or over) have almost half the odds of being fuel poor compared to younger households. This may be due to the fact that such households are likely to have lower housing costs (the LIHC indicator is based on after housing costs income) and therefore a higher level of after-housing costs disposable income, compared to younger households.
- The odds of being fuel poor more than doubles for households where the household reference person (HRP) is either unemployed or inactive[7] compared to households where the HRP is employed. Retired HRPs also show a 27% increase in the odds of being fuel poor compared to their employed counterparts.
- In addition, having a retired or unemployed partner increases the odds of being fuel poor more than three-fold compared to households in which the partner is in some form of employment.
- Households on means-tested benefits also have increased odds of being fuel poor – an almost four-fold increase is seen for households on mean-tested benefits compared to those not on benefits.
- Households off the gas grid network have around 40% lower odds of being fuel poor compared to households on the gas network. This may seem somewhat counter-intuitive as one would expect households off the gas grid to have alternative, more expensive fuel systems (such as electrical or oil fired systems) and so face an increased likelihood of being fuel poor. However, around three quarters of the off-grid population have incomes that take them above the income threshold defined in the LIHC measure. This is illustrated by the fact that the propensity to be fuel poor within the off-grid population is very similar to that in the on-grid population (14% vs. 11% respectively).
- Of the dwelling types, households living in bungalows or detached properties have the highest odds of being fuel poor (3.5 times that of flats) followed by households living in semi-detached or terraced properties (odds ratios of 3.2 and 2.3 respectively). Also, households living in older properties, generally tend to have increased odds of being fuel poor compared to more recently built properties.

[7] Economically inactive people include those who are in full time education, the permanently sick or disabled, or those looking after the family or home or engaged any other activity.

- The odds of being fuel poor increase notably for properties with floor spaces above $50m^2$. Households living in properties larger of $110m^2$ or more have the largest odds of being fuel poor, followed by those living in properties with floor spaces between $90m^2$-$109m^2$ and $70m^2$-$89m^2$ (with odds ratios of 17.9, 11.7 and 7.0 respectively).
- Under-occupied households have reduced odds of being fuel poor - around half the odds of households which are not under-occupied. [8]
- Households living in privately rented accommodation have over twice the odds of being fuel poor compared to households in social housing.
- The main fuel types used by a household also significantly affect the odds of being fuel poor. Those using the more expensive electrical systems have the highest odds of being fuel poor – 2.5 times the odds of those using gas fired systems.
- Households in receipt of disability benefits also have reduced odds of being fuel poor.
- And finally, households that have non-condensing boilers all have increased odds of being fuel poor.

[8] Some dwellings are considered excessive in size for the number of occupants that live there. In these cases, the house is assumed to be "under-occupied", that is only a proportion of the dwelling will need heating.



* Not statistically significant

Figure 1: Effect of characteristics on the odds of a household to be living in fuel poverty, 2010

Reviewing the importance of these household and dwelling characteristics on the odds of being fuel poor, the largest and most significant[9] increases in the odds are seen for households living in larger and older properties. Households on means tested benefits are also at a significant risk of being fuel poor, as are households in which the main reference person or their partner is not in active employment. The largest and most significant decreases in the odds of being fuel poor are seen in households that are in receipt of some form of Disability Living Allowance or Attendance Allowance or if the property is under occupied.

It is possible to convert the odds effects described above into probabilities of being fuel poor for households with any particular combinations of characteristics from the model[10]. The individual effects (see Annex 3B) are multiplied together to find an overall effect which is then converted to a probability[11]. Box 1 provides an example.

Box 1: calculating the probability of being fuel poor

Take the following households:

Household A	Odds	Household B	Odds
3 person household	0.98	2 person household	1.31
Unemployed HRP	2.59	Employed HRP	1.00
Unemployed partner	3.07	Employed partner	1.00
Income related benefits	3.87	No income related benefits	1.00
Terrace property	2.32	Flat	1.00
1940's build	3.45	1990's build	1.00
Property size: $70m^2$-$89m^2$	7.05	Property size: $70m^2$-$89m^2$	7.05
Not under-occupying	1.00	Under-occupying	0.50
With loft insulation	1.00	No loft	0.97
No boiler	2.78	Combination boiler	1.26

The remaining characteristics are the reference characteristics specified in the

[9] The rank order of significance for a variable is shown by the magnitude of the corresponding Wald statistic. High Wald statistics imply an increased significance to the model (see model output statistics in Annex 3B).
[10] Note, any number of variable combinations can be selected here as shown in the proceeding example.
[11] Probability = odds/(1+odds)

model.

Household A	**Odds**	**Household B**	**Odds**
Multiplied effects	4730.60	Multiplied effects	5.64

The model gives the odds of being fuel poor for the **reference household** of 0.0001 or 0.01% (Annex 2B).

The example **Household A** has 4730.60 times these odds of being fuel poor (4730.60*0.0001) = 0.4736, or (0.4736/[1+0.4736]) = 32.1%; and **Household B** has 5.64 times these odds of being fuel poor (5.64*0.0001) = 0.000564, or (0.000564/[1+0.000564]) = 0.1%.

So Household A's probability of being fuel poor is 32.1% compared to Household B's 0.1% probability and the overall population average of 11.1%.

Probability thresholds

Table 11 shows the number of households captured as fuel poor under different probability thresholds from this model, including the false positives and negatives. The threshold can be set at different intervals. If the threshold were set at 0.5, it would mean that any household with a probability greater than 0.5 was likely to be fuel poor. A false positive occurs when the model classifies a household as being fuel poor, when it is not. Similarly, a false negative is the misclassification of a household as *not* fuel poor, when in fact it is. Setting the threshold low gives a high proportion of false positives. Increasing the threshold reduces the number of false positives, but also increases the false negatives.

Table 11: The number of households classed as fuel poor by different modelled probability thresholds

Probability Threshold	Population (000)	Proportion of household population (%)	Modelled false positives (%)	Modelled false negatives (%)
25% Threshold				
Modelled Fuel Poor	2,704	12.5%	54.5%	6.2%
Actual Fuel Poor	1,228			
50% Threshold				

Probability Threshold	Population (000)	Proportion of household population (%)	Modelled false positives (%)	Modelled false negatives (%)
Modelled Fuel Poor	859	4.0%	33.1%	8.8%
Actual Fuel Poor	574			
<u>75% Threshold</u>				
Modelled Fuel Poor	195	0.9%	16.4%	10.4%
Actual Fuel Poor	163			
Total Number of Fuel Poor Households	2,394			
Total Number of Households in England, 2008 - 2010	21,554			

Alternative models for households living in fuel poverty

The model described above dropped the wall insulation and SAP variables due to practical considerations, as these characteristics can be difficult to identify without fully surveying a dwelling first. The following section considers how these variables relate to fuel poor households if they are reinserted into the model.

The first alternative model (LIHC Alternative 1) considers the inclusion of wall insulation in the modelling. The remaining variables all stay as outlined in Table 10, with the exception of loft insulation which is now removed from the model due to statistical non-significance. Here the regression output shows that households with un-insulated cavity walls increase the odds of being fuel poor by 2.1 and households with (un-insulated) solid walls increase the odds of being fuel poor by 2.6 – compared to households *with* cavity wall insulation.

The effects of the all other variables in the model broadly remain similar, with the exception of dwelling age. Here it appears that once wall insulation is accounted for, the effects on the odds of being fuel poor for households living in pre-1919 properties reduce notably, and the odds for households living in semi-detached or detached properties or bungalows increase notably. This is likely due to the fact that much of the older housing stock predominantly has solid walls and post-war properties have cavity walls, thus reducing the effects of the age of older properties once the actual wall type is taken into account.

The second alternative model (LIHC Alternative 2) considers the inclusion of SAP (05) in the model. Including the SAP variable in the model renders the following variables non-significant: loft insulation, main fuel type and boiler type. These variables form part of the SAP score. All other variables remain as outlined in Table 10.

Overall, the inclusion of the SAP variable significantly improves the model fit and shows a considerable effect on the odds of being fuel poor. Compared to households living in properties with a SAP rating of A, B or C, household living in E rated properties have 78 times the odds of being fuel poor, and households living in F/G rated properties, have a 150 fold increase in their odds of being fuel poor. With the SAP rating taken into account, the effects of the larger and older dwelling types reduce notably. However, it should be noted that as SAP is a construct of many of the basic characteristics of a property, it is difficult to precisely identify the main variables driving these results.

Details for both these alternative models can be found in Annex 3C.

Modelled output for households in severe fuel poverty

A similar modelling approach was also applied to model households identified as being in severe fuel poverty.

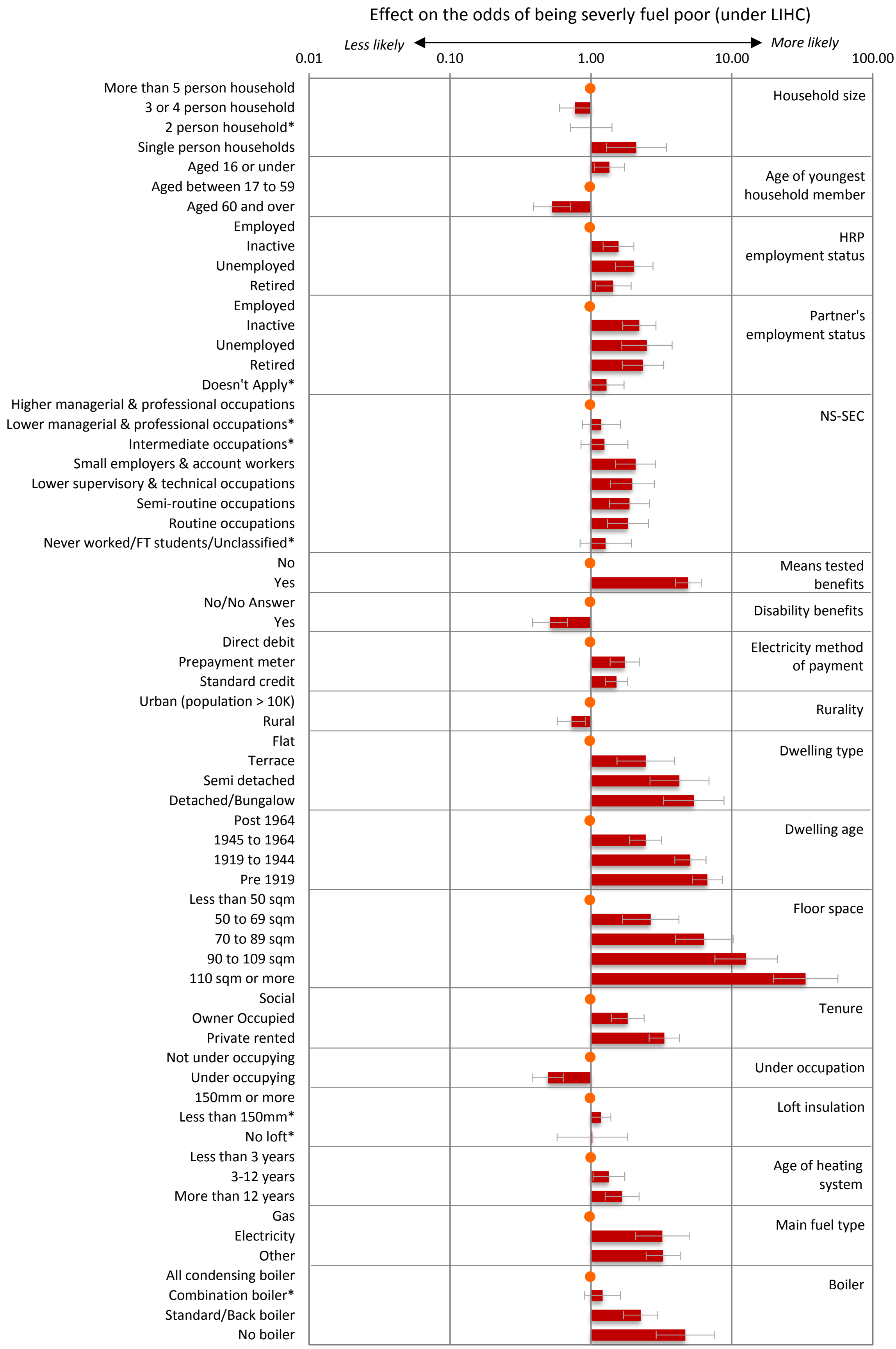
shows the final modelled outcome for predicting households that are in severe fuel poverty.

The size of the effects, the corresponding 95% confidence intervals, Wald statistics and validation tests for the model can be found in Annex 3D.

The regression analysis for households in severe fuel poverty broadly shows similar patterns as seen earlier for households in fuel poverty. The main difference in this case is that the variable rurality is now significant in predicting those households in deep fuel poverty. However, whether or not a household is on the gas network is now statistically non-significant.

Holding all other characteristics constant and equal it is apparent from this model that households living in a rural setting face reduced odds of being deeply fuel poor (almost 30% lower) compared to similar households in an urban setting.

In general, the effect sizes for the remaining common variables across both models (LIHC model and the deep fuel poor model) are broadly similar. However the age and size of a property do have considerably larger effects on the odds of a household being *deepest* in fuel poverty compared to households that are fuel poor.



* Not statistically significant

Figure 2: Effect of various characteristics on the odds of being in severe fuel poverty, 2010

The impact of gas heating: further explanation

The modelled results for those in fuel poverty (LIHC) showed that the effect of being off the gas grid actually reduced the likelihood of being fuel poor while at the same time, the effects of non-gas main fuel types seems to *increase* the likelihood of being fuel poor. However, the significance to the model (as measured by the Wald statistics) is greater for the non-gas heating fuels variable. As such it is possible that there are other aspects of the model that are more closely linked to being off the gas grid (for example, income) that may be explaining the reason why this aspect is shown to decrease the probability of being fuel poor. Further work is needed to properly understand this point. What is clear when looking at the breakdown of households in fuel poverty is that a greater proportion of households not using gas for heating are in fuel poverty see Figure 3.

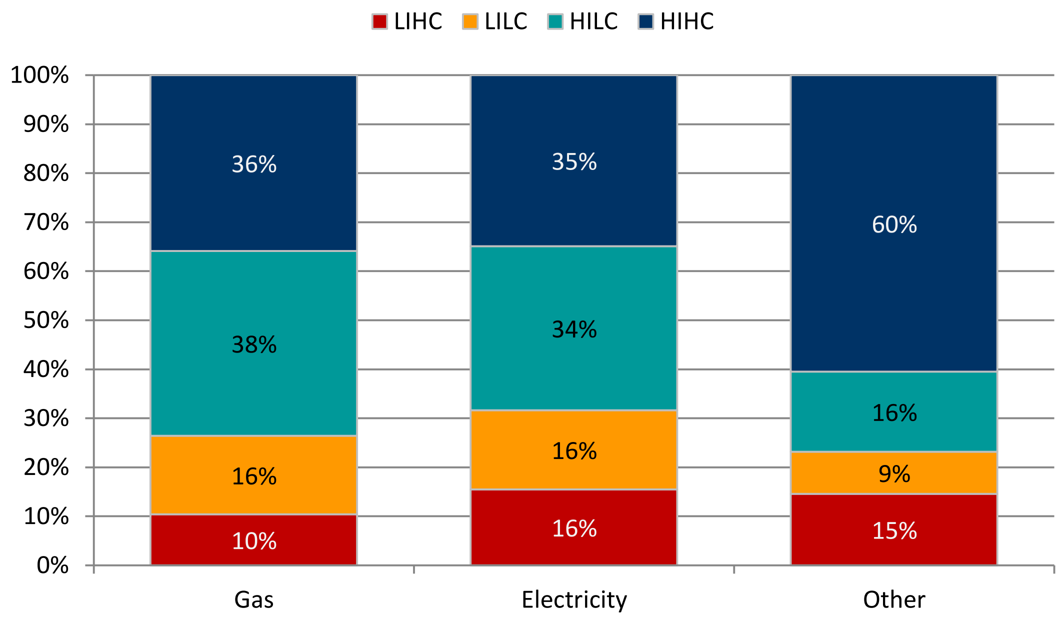


Figure 3: Distribution of households across main heating fuel types

Annex 3A: Modelling methodology

Several approaches have been trialled for the regression modelling with the aim of arriving at a consistent and valid model that can be generalised over the existing population, as well as future ones.

The initial approach modelled the individual EHS datasets for the past three years (2010, 2009 and 2008) in order to assess whether these converged to a common set of predicator variables. The results showed that while the model variables and patterns were broadly similar for the 2008 and 2010 datasets, the 2009 dataset yielded a markedly different set of outcomes. The most notable finding from the modelled outcome of the 2009 dataset was that any inclusion of SAP in the modelling rendered the entire model invalid. It was, therefore, not possible to arrive at a consistent model across all three years.

The next modelling approach combined the 2009 and 2010 EHS datasets and covered the period 2008-2010 (as the EHS datasets are a combination of two years – the current year and the one before). Earlier years were not considered for the analysis as a common set of initial variables is not available pre-2007.

Two models were run from this dataset:

i) The first, modelled the likelihood of households being fuel poor under the LIHC measure; and
ii) The second modelled the likelihood of households being in severe fuel poverty - the third of the fuel poor household population with the highest fuel poverty gaps.

A series of logistic regressions was carried out for modelling i) and ii) above using the ‘forced entry’ method. In each case, the resulting models were examined to assess whether there were any statistically insignificant (redundant) variables. At each stage, the non-significant variables were removed from the model, and the process repeated until a final parsimonious model was reached.

On advice from the Office for National Statistics (ONS) methodology unit, a number of categories within the variables considered in the above modelling were aggregated to further simplify the model. Only categories within the same variable and with similar effect sizes were combined in this way.

The initial set of variables considered, and categories within these, are set out in Table 12.

Table 12: Variables considered in the modelling

Variable	Variable catagories
Family Composition	Couple, no dependent child(ren): Baseline
	Couple with dependent child(ren)
	Lone parent with dependent child(ren)
	One person
	Other multi-person households
Household size	Number of persons in the household =5: Baseline
	Number of persons in the household =3 or 4
	Number of persons in the household =2
	Number of persons in the household =1
Age band of youngest person in household	Aged <= 16
	Aged between 16 to 59: Baseline
	Aged 60 and over
Individual(s) disabled or with chronic illness	No disabled household members or unknown: Baseline
	Disabled member in the household
Employment status of household reference person	HRP - Employed: Baseline
	HRP - Inactive
	HRP - Unemployed
	HRP - Retired
Employment status (primary) of partner	Partner - Employed: Baseline
	Partner - Inactive
	Partner - Unemployed
	Partner - Retired
	Partner - Doesn't apply
National Statistics Socio-Economic Classification	Higher managerial and professional occupations: Baseline
	Lower managerial and professional occupations
	Intermediate occupations
	Small employers and account workers
	Lower supervisory and technical occupations
	Semi-routine occupations
	Routine occupations
	Never worked, long term unemployed and unclassified
Household on means tested benefits/tax credit	No: Baseline
	Yes
Attendance allowance or DLA mobility/care component	No or No Answer: Baseline
	Yes
Method of payment - electricity	Direct debit: Baseline
	Pre payment
	Standard credit
Method of payment - gas	Direct debit: Baseline
	Pre payment
	Standard credit
	N/A = No gas
Government office region	South East: Baseline
	East England
	East Midlands
	London
	North East
	North West
	South West
	West Midlands
	Yorkshire and the Humber

Variable	Variable catagories
Rurality - morphology (COA)	Urban: Baseline Rural
Whether dwelling is on the gas network	On gas network: Baseline Not on gas network
Dwelling type	Flat: Baseline Terrace Semi detached Detached/Bungalow
Dwelling age	Post1964: Baseline 1945 to 1964 1919 to 1944 Pre 1919
Floor area	Less than 50 sqm: Baseline 50 to 69 sqm 70 to 89 sqm 90 to 109 sqm 110 sqm or more
Total no of bedrooms	1 bedrooms: Baseline 4 bedroom properties 3 bedroom properties 2 bedroom properties More than 5 bedroom properties
Tenure	Social: Baseline Owner occupied Private rented
Under occupancy	Not under occupying: Baseline Under occupying
Energy efficiency rating band (SAP 2005)	A, B or C: Baseline D E F or G
Loft insulation thickness	150mm or more: Baseline Less than 150mm No loft
Type of wall and insulation	Cavity with insulation: Baseline Cavity uninsulated Other
Main heating fuel	Gas: Baseline Electricity Other
Age of heating system	Less than 3 years: Baseline 3-12 years More than 12 years
Type of boiler	All condensing boiler: Baseline Combination boiler Standard/Back boiler No boiler
Main heating system	Central heating: Baseline Non-central heating
Water heating system	With central heating: Baseline Other

Annex 3B: Regression results and model validation (LIHC)

Table 13: Model estimates for LIHC households

Low Income High Costs - Variable	Variable catagories	Effect on the odds	95% Confidence interval		Sig. (0.05)	Wald	B	S.E.
			Lower limit	Upper limit				
Household size	More than 5 person household	1.00						
	3 or 4 person household*	0.98	0.83	1.16	0.81	0.06	-0.02	0.09
	2 person household	1.31	1.06	1.63	0.01	6.12	0.27	0.11
	Single person households	3.77	2.78	5.12	0.00	72.55	1.33	0.16
Age band of youngest person in household	Aged 16 or under	1.18	1.02	1.37	0.03	4.67	0.17	0.08
	Aged between 17 to 59	1.00						
	Aged 60 and over	0.52	0.43	0.63	0.00	47.02	-0.65	0.10
Employment status of household reference person	Employed	1.00						
	Inactive	2.13	1.84	2.46	0.00	102.44	0.76	0.07
	Unemployed	2.59	2.13	3.13	0.00	94.14	0.95	0.10
	Retired	1.27	1.06	1.52	0.01	6.71	0.24	0.09
Employment status (primary) of partner	Employed	1.00						
	Inactive	2.39	2.01	2.83	0.00	98.41	0.87	0.09
	Unemployed	3.07	2.36	4.00	0.00	69.28	1.12	0.13
	Retired	3.21	2.62	3.95	0.00	123.56	1.17	0.11
	Doesn't Apply	1.30	1.09	1.54	0.00	8.70	0.26	0.09
National Statistics Socio-Economic Classification	Higher managerial & professional occupations	1.00						
	Lower managerial & professional occupations	1.42	1.15	1.75	0.00	10.68	0.35	0.11
	Intermediate occupations	1.94	1.53	2.46	0.00	29.83	0.66	0.12
	Small employers & account workers	2.46	1.96	3.09	0.00	60.47	0.90	0.12
	Lower supervisory & technical occupations	2.12	1.68	2.69	0.00	39.53	0.75	0.12
	Semi-routine occupations	2.56	2.06	3.16	0.00	74.08	0.94	0.11
	Routine occupations	2.51	2.02	3.12	0.00	68.16	0.92	0.11
	Never worked/FT students/Unclassified	2.16	1.67	2.80	0.00	33.93	0.77	0.13
Household on means tested benefits/tax credit	No	1.00						
	Yes	3.87	3.41	4.41	0.00	424.20	1.35	0.07
Attendance allowance or DLA mobility/care component	No/No Answer	1.00						
	Yes	0.35	0.30	0.42	0.00	139.65	-1.04	0.09
Method of payment - electricity	Direct debit	1.00						
	Prepayment meter	2.14	1.87	2.46	0.00	117.64	0.76	0.07
	Standard credit	1.73	1.54	1.93	0.00	88.95	0.55	0.06
Whether dwelling is on the gas network	On network	1.00						
	Not on network	0.57	0.45	0.74	0.00	18.80	-0.56	0.13
Dwelling type	Flat	1.00						
	Terrace	2.32	1.83	2.96	0.00	47.50	0.84	0.12
	Semi detached	3.22	2.51	4.12	0.00	85.99	1.17	0.13
	Detached/Bungalow	3.52	2.72	4.55	0.00	92.44	1.26	0.13
Dwelling age	Post 1964	1.00						
	1945 to 1964	2.26	1.98	2.58	0.00	143.71	0.82	0.07
	1919 to 1944	3.45	3.00	3.98	0.00	295.96	1.24	0.07
	Pre 1919	3.89	3.38	4.48	0.00	356.47	1.36	0.07
Floor area	Less than 50 sqm	1.00						
	50 to 69 sqm	2.86	2.27	3.60	0.00	78.83	1.05	0.12
	70 to 89 sqm	7.05	5.51	9.01	0.00	242.98	1.95	0.13
	90 to 109 sqm	11.73	8.87	15.49	0.00	299.64	2.46	0.14
	110 sqm or more	17.89	13.31	24.06	0.00	364.67	2.88	0.15
Tenure	Social	1.00						
	Owner Occupied	1.17	1.01	1.36	0.03	4.49	0.16	0.08
	Private rented	2.49	2.15	2.87	0.00	156.71	0.91	0.07
Under occupancy	Not under occupying	1.00						
	Under occupying	0.50	0.42	0.58	0.00	76.23	-0.70	0.08
Loft insulation thickness	150mm or more	1.00						
	Less than 150mm	1.21	1.10	1.34	0.00	14.63	0.19	0.05
	No loft*	0.97	0.73	1.30	0.86	0.03	-0.03	0.15
Age of heating system	Less than 3 years	1.00						
	3-12 years	1.16	1.01	1.34	0.04	4.32	0.15	0.07
	More than 12 years	1.72	1.46	2.02	0.00	43.49	0.54	0.08
Main heating fuel	Gas	1.00						
	Electricity	2.48	1.78	3.45	0.00	28.92	0.91	0.17
	Other	2.35	1.77	3.13	0.00	34.23	0.85	0.15
Type of boiler	All condensing boiler	1.00						
	Combination boiler	1.26	1.07	1.47	0.00	8.15	0.23	0.08
	Standard/Back boiler	1.77	1.51	2.07	0.00	50.90	0.57	0.08
	No boiler	2.78	2.05	3.77	0.00	43.27	1.02	0.16
Model constant	Constant	0.0001			0.00	1390.81	-9.08	0.24

* Not statistically significant

Model Validation

The Hosmer and Lemeshow test provides an overall fit of the logistic regression model and tests whether the difference between the observed and expected values is statistically significant. A finding of non-significance implies that the model adequately fits the data. At a 5% level of significance, this test is found to be insignificant (p-value: 0.537) and therefore the logistic regression model above is valid.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	7.001	8	0.537

The accuracy of the model in discriminating between fuel poor and non-fuel poor households is evaluated using the Receiver Operating Characteristic (ROC) curve. The Area under this curve (AUC), known as the c-statistic, can range from 0.5 (no predictive ability) to 1 (perfect discrimination). The statistically significant value of 0.849 shows this model offers a very good level of discrimination.

Area Under the Curve

Area	Std. Error	Asymptotic Sig	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
0.849	0.004	0.000	0.842	0.857

Annex 3C: alternative model results

Table 14: Alternative model 1 estimates

Low Income High Costs: Alternative 1 - Variable	Variable catagories	Effect on the odds	95% Confidence interval		Sig. (0.05)	Wald	B	S.E.
			Lower limit	Upper limit				
Household size	More than 5 person household	1.00						
	3 or 4 person household*	1.01	0.85	1.19	0.95	0.00	0.01	0.09
	2 person household	1.36	1.10	1.69	0.01	7.80	0.31	0.11
	Single person households	3.97	2.92	5.40	0.00	77.30	1.38	0.16
Age band of youngest person in household	Aged 16 or under*	1.16	1.00	1.35	0.06	3.60	0.15	0.08
	Aged between 17 to 59	1.00						
	Aged 60 and over	0.53	0.44	0.63	0.00	44.77	-0.64	0.10
Employment status of household reference person	Employed	1.00						
	Inactive	2.19	1.89	2.54	0.00	109.06	0.78	0.08
	Unemployed	2.58	2.12	3.13	0.00	91.74	0.95	0.10
	Retired	1.31	1.09	1.57	0.00	8.45	0.27	0.09
Employment status (primary) of partner	Employed	1.00						
	Inactive	2.43	2.05	2.89	0.00	101.58	0.89	0.09
	Unemployed	3.01	2.31	3.93	0.00	65.42	1.10	0.14
	Retired	3.27	2.65	4.02	0.00	125.14	1.18	0.11
	Doesn't Apply	1.29	1.08	1.53	0.00	8.15	0.25	0.09
National Statistics Socio-Economic Classification	Higher managerial & professional occupations	1.00						
	Lower managerial & professional occupations	1.44	1.17	1.78	0.00	11.44	0.37	0.11
	Intermediate occupations	2.00	1.58	2.54	0.00	32.22	0.69	0.12
	Small employers & account workers	2.55	2.03	3.20	0.00	64.27	0.94	0.12
	Lower supervisory & technical occupations	2.20	1.74	2.79	0.00	42.88	0.79	0.12
	Semi-routine occupations	2.67	2.16	3.32	0.00	80.39	0.98	0.11
	Routine occupations	2.62	2.11	3.27	0.00	73.89	0.96	0.11
	Never worked/FT students/Unclassified	2.16	1.66	2.81	0.00	33.48	0.77	0.13
Household on means tested benefits/tax credit	No	1.00						
	Yes	4.00	3.52	4.56	0.00	436.90	1.39	0.07
Attendance allowance or DLA mobility/care component	No/No Answer	1.00						
	Yes	0.35	0.30	0.42	0.00	139.59	-1.04	0.09
Method of payment - electricity	Direct debit	1.00						
	Prepayment meter	2.11	1.84	2.43	0.00	111.28	0.75	0.07
	Standard credit	1.70	1.52	1.91	0.00	82.75	0.53	0.06
Whether dwelling is on the gas network	On network	1.00						
	Not on network	0.55	0.43	0.71	0.00	21.30	-0.60	0.13
Dwelling type	Flat	1.00						
	Terrace	2.77	2.32	3.31	0.00	126.01	1.02	0.09
	Semi detached	4.06	3.36	4.91	0.00	211.08	1.40	0.10
	Detached/Bungalow	4.50	3.68	5.51	0.00	214.14	1.50	0.10
Dwelling age	Post 1964	1.00						
	1945 to 1964	2.34	2.04	2.68	0.00	150.93	0.85	0.07
	1919 to 1944	2.93	2.52	3.41	0.00	198.21	1.08	0.08
	Pre 1919	2.65	2.24	3.14	0.00	126.98	0.98	0.09
Floor area	Less than 50 sqm	1.00						
	50 to 69 sqm	2.84	2.25	3.59	0.00	77.82	1.05	0.12
	70 to 89 sqm	7.17	5.60	9.17	0.00	246.09	1.97	0.13
	90 to 109 sqm	12.08	9.14	15.98	0.00	305.09	2.49	0.14
	110 sqm or more	18.31	13.60	24.66	0.00	367.10	2.91	0.15
Tenure	Social	1.00						
	Owner Occupied*	1.13	0.98	1.32	0.10	2.72	0.13	0.08
	Private rented	2.31	2.00	2.67	0.00	131.02	0.84	0.07
Under occupancy	Not under occupying	1.00						
	Under occupying	0.49	0.41	0.57	0.00	80.42	-0.72	0.08
Wall insulation	Cavity with insulation	1.00						
	Cavity uninsulated	2.08	1.83	2.35	0.00	132.89	0.73	0.06
	Other	2.61	2.26	3.02	0.00	169.34	0.96	0.07
Age of heating system	Less than 3 years	1.00						
	3-12 years*	1.15	0.99	1.33	0.06	3.56	0.14	0.07
	More than 12 years	1.71	1.45	2.01	0.00	41.80	0.54	0.08
Main heating fuel	Gas	1.00						
	Electricity	2.61	1.87	3.64	0.00	31.90	0.96	0.17
	Other	2.38	1.78	3.17	0.00	34.68	0.87	0.15
Type of boiler	All condensing boiler	1.00						
	Combination boiler	1.25	1.07	1.47	0.01	7.80	0.23	0.08
	Standard/Back boiler	1.76	1.50	2.07	0.00	49.20	0.57	0.08
	No boiler	2.71	1.99	3.68	0.00	40.65	1.00	0.16
Model constant	Constant	0.0001			0.00	1693.70	-9.68	0.24

* Not statistically significant

Table 15: Alternative model 2 estimates

Low Income High Costs: Alternative 2 - Variable	Variable catagories	Effect on the odds	95% Confidence interval Lower limit	Upper limit	Sig. (0.05)	Wald	B	S.E.
Household size	More than 5 person household	1.00						
	3 or 4 person household*	0.97	0.81	1.16	0.74	0.11	-0.03	0.09
	2 person household	1.33	1.06	1.67	0.01	6.18	0.29	0.12
	Single person households	4.05	2.94	5.58	0.00	73.17	1.40	0.16
Age band of youngest person in household	Aged 16 or under*	1.17	1.00	1.37	0.05	3.81	0.16	0.08
	Aged between 17 to 59	1.00						
	Aged 60 and over	0.51	0.42	0.62	0.00	46.83	-0.68	0.10
Employment status of household reference person	Employed	1.00						
	Inactive	2.41	2.07	2.81	0.00	124.32	0.88	0.08
	Unemployed	2.67	2.18	3.29	0.00	88.07	0.98	0.10
	Retired	1.28	1.06	1.54	0.01	6.78	0.25	0.10
Employment status (primary) of partner	Employed	1.00						
	Inactive	2.55	2.13	3.04	0.00	106.42	0.94	0.09
	Unemployed	3.45	2.61	4.56	0.00	75.29	1.24	0.14
	Retired	3.39	2.74	4.18	0.00	128.17	1.22	0.11
	Doesn't Apply	1.35	1.13	1.62	0.00	10.99	0.30	0.09
National Statistics Socio-Economic Classification	Higher managerial & professional occupations	1.00						
	Lower managerial & professional occupations	1.41	1.14	1.75	0.00	10.01	0.35	0.11
	Intermediate occupations	2.01	1.58	2.56	0.00	31.60	0.70	0.12
	Small employers & account workers	2.63	2.09	3.32	0.00	66.76	0.97	0.12
	Lower supervisory & technical occupations	2.17	1.71	2.76	0.00	40.32	0.78	0.12
	Semi-routine occupations	2.68	2.15	3.33	0.00	77.91	0.98	0.11
	Routine occupations	2.64	2.11	3.30	0.00	71.96	0.97	0.11
	Never worked/FT students/Unclassified	2.22	1.70	2.91	0.00	33.74	0.80	0.14
Household on means tested benefits/tax credit	No	1.00						
	Yes	4.37	3.83	5.00	0.00	469.96	1.48	0.07
Attendance allowance or DLA mobility/care component	No/No Answer	1.00						
	Yes	0.32	0.27	0.39	0.00	150.65	-1.13	0.09
Method of payment - electricity	Direct debit	1.00						
	Prepayment meter	2.23	1.93	2.58	0.00	118.22	0.80	0.07
	Standard credit	1.73	1.54	1.94	0.00	83.54	0.55	0.06
Whether dwelling is on the gas network	On network	1.00						
	Not on network	0.82	0.71	0.95	0.01	6.60	-0.20	0.08
Dwelling type	Flat	1.00						
	Terrace	2.17	1.80	2.61	0.00	67.84	0.77	0.09
	Semi detached	2.15	1.77	2.60	0.00	60.29	0.76	0.10
	Detached/Bungalow	1.87	1.53	2.29	0.00	36.57	0.63	0.10
Dwelling age	Post 1964	1.00						
	1945 to 1964	1.36	1.18	1.57	0.00	18.39	0.31	0.07
	1919 to 1944	1.58	1.36	1.83	0.00	35.30	0.46	0.08
	Pre 1919	1.41	1.21	1.64	0.00	19.69	0.35	0.08
Floor area	Less than 50 sqm	1.00						
	50 to 69 sqm	2.68	2.11	3.41	0.00	65.12	0.99	0.12
	70 to 89 sqm	6.46	5.02	8.31	0.00	209.88	1.87	0.13
	90 to 109 sqm	11.22	8.42	14.95	0.00	272.60	2.42	0.15
	110 sqm or more	18.52	13.66	25.12	0.00	352.69	2.92	0.16
Tenure	Social	1.00						
	Owner Occupied*	0.87	0.74	1.01	0.07	3.24	-0.14	0.08
	Private rented	1.95	1.68	2.26	0.00	76.46	0.67	0.08
Under occupancy	Not under occupying	1.00						
	Under occupying	0.46	0.39	0.54	0.00	88.51	-0.78	0.08
Age of heating system	Less than 3 years	1.00						
	3-12 years*	1.14	1.00	1.30	0.05	3.71	0.13	0.07
	More than 12 years	1.35	1.18	1.55	0.00	18.83	0.30	0.07
Energy efficiency rating band (SAP 2005)	A, B or C	1.00						
	D	13.48	8.62	21.09	0.00	129.99	2.60	0.23
	E	64.40	40.96	101.23	0.00	325.65	4.17	0.23
	F or G	123.50	77.15	197.68	0.00	402.63	4.82	0.24
Model constant	Constant	0.0000			0.00	1192.57	-10.97	0.32

* Not statistically significant

Annex 3D: regression results and model validation (severe fuel poverty)

Table 16: model estimates for households in deepest fuel poverty

Severe fuel poverty - Variable	Variable catagories	Effect on the odds	95% Confidence interval		Sig. (0.05)	Wald	B	S.E.
			Lower limit	Upper limit				
Household size	More than 5 person household	1.00						
	3 or 4 person household	0.77	0.60	0.99	0.04	4.03	-0.26	0.13
	2 person household*	1.01	0.72	1.41	0.97	0.00	0.01	0.17
	Single person households	2.10	1.29	3.43	0.00	8.93	0.74	0.25
Age band of youngest person in household	Aged 16 or under	1.35	1.06	1.73	0.02	5.74	0.30	0.13
	Aged between 17 to 59	1.00						
	Aged 60 and over	0.53	0.39	0.72	0.00	16.58	-0.63	0.16
Employment status of household reference person	Employed	1.00						
	Inactive	1.57	1.22	2.01	0.00	12.45	0.45	0.13
	Unemployed	2.03	1.49	2.76	0.00	20.15	0.71	0.16
	Retired	1.44	1.08	1.93	0.01	6.09	0.37	0.15
Employment status (primary) of partner	Employed	1.00						
	Inactive	2.20	1.68	2.89	0.00	32.67	0.79	0.14
	Unemployed	2.50	1.66	3.76	0.00	19.10	0.91	0.21
	Retired	2.34	1.67	3.29	0.00	24.37	0.85	0.17
	Doesn't Apply*	1.29	0.97	1.72	0.08	3.05	0.25	0.15
National Statistics Socio-Economic Classification	Higher managerial & professional occupations	1.00						
	Lower managerial & professional occupations*	1.19	0.87	1.62	0.28	1.15	0.17	0.16
	Intermediate occupations*	1.25	0.85	1.83	0.26	1.28	0.22	0.20
	Small employers & account workers	2.08	1.50	2.88	0.00	19.17	0.73	0.17
	Lower supervisory & technical occupations	1.97	1.37	2.81	0.00	13.63	0.68	0.18
	Semi-routine occupations	1.88	1.35	2.60	0.00	14.27	0.63	0.17
	Routine occupations	1.83	1.31	2.56	0.00	12.41	0.60	0.17
	Never worked/FT students/Unclassified*	1.27	0.84	1.93	0.26	1.26	0.24	0.21
Household on means tested benefits/tax credit	No	1.00						
	Yes	4.91	3.98	6.05	0.00	220.14	1.59	0.11
Attendance allowance or DLA mobility/care component	No/No Answer	1.00						
	Yes	0.51	0.39	0.68	0.00	20.85	-0.67	0.15
Method of payment - electricity	Direct debit	1.00						
	Prepayment meter	1.74	1.37	2.21	0.00	20.62	0.55	0.12
	Standard credit	1.52	1.27	1.82	0.00	20.34	0.42	0.09
Rurality	Urban (population > 10K)	1.00						
	Rural	0.73	0.58	0.91	0.01	7.45	-0.32	0.12
Dwelling type	Flat	1.00						
	Terrace	2.45	1.53	3.92	0.00	13.97	0.90	0.24
	Semi detached	4.25	2.63	6.87	0.00	34.78	1.45	0.25
	Detached/Bungalow	5.37	3.28	8.78	0.00	44.66	1.68	0.25
Dwelling age	Post 1964	1.00						
	1945 to 1964	2.44	1.88	3.18	0.00	44.44	0.89	0.13
	1919 to 1944	5.08	3.94	6.56	0.00	156.54	1.63	0.13
	Pre 1919	6.70	5.25	8.53	0.00	236.42	1.90	0.12
Floor area	Less than 50 sqm	1.00						
	50 to 69 sqm	2.65	1.68	4.20	0.00	17.32	0.98	0.23
	70 to 89 sqm	6.38	3.99	10.20	0.00	59.69	1.85	0.24
	90 to 109 sqm	12.62	7.58	21.02	0.00	94.99	2.54	0.26
	110 sqm or more	33.35	19.70	56.46	0.00	170.40	3.51	0.27
Tenure	Social	1.00						
	Owner Occupied	1.82	1.39	2.39	0.00	19.18	0.60	0.14
	Private rented	3.32	2.59	4.27	0.00	89.10	1.20	0.13
Under occupancy	Not under occupying	1.00						
	Under occupying	0.49	0.38	0.64	0.00	30.08	-0.71	0.13
Loft insulation thickness	150mm or more	1.00						
	Less than 150mm*	1.17	1.00	1.39	0.06	3.65	0.16	0.08
	No loft*	1.02	0.57	1.83	0.93	0.01	0.02	0.29
Age of heating system	Less than 3 years	1.00						
	3-12 years	1.34	1.04	1.74	0.03	4.96	0.29	0.13
	More than 12 years	1.66	1.26	2.20	0.00	13.04	0.51	0.14
Main heating fuel	Gas	1.00						
	Electricity	3.21	2.07	4.98	0.00	27.14	1.17	0.22
	Other	3.26	2.46	4.30	0.00	68.89	1.18	0.14
Type of boiler	All condensing boiler	1.00						
	Combination boiler	1.21	0.90	1.62	0.21	1.61	0.19	0.15
	Standard/Back boiler	2.25	1.70	2.98	0.00	32.52	0.81	0.14
	No boiler	4.67	2.91	7.51	0.00	40.61	1.54	0.24
Model constant	Constant	0.0000			0.00	709.17	-11.37	0.43

* Not statistically significant

Model Validation

The Hosmer and Lemeshow test provides an overall fit of the logistic regression model and tests whether the difference between the observed and expected values is statistically significant. A finding of non-significance implies that the model adequately fits the data. At a 5% level of significance, this test is found to be insignificant (p-value: 0.064) and therefore the logistic regression model above is valid.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	14.848	8	0.062

The accuracy of the model to discriminate between fuel poor and non-fuel poor households is evaluated using the Receiver Operating Characteristic (ROC) curve. The Area under this curve (AUC), known as the c-statistic, can range from 0.5 (no predictive ability) to 1 (perfect discrimination). The statistically significant value of 0.901 shows this model offers a very good level of discrimination.

Area Under the Curve

Area	Std. Error	Asymptotic Sig	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
0.902	0.004	0.000	0.893	0.911

Section Four: Fuel poverty projections

This section sets out the methodology for and results of our work to make future projections of fuel poverty. These projections have been used extensively in developing our analytical framework both through helping us to understand how the level of fuel poverty is expected to change in response to changes in energy prices, incomes and policy interventions and through providing the foundation for developing the FP-MACC (see Section Five for further details).

The following sections set out:

- An overview of the modelling methodology;
- The assumptions about energy prices, incomes and government policies that are used to produce the illustrative projections fuel poverty in future;
- The projections methodology;
- The results of some illustrative projections based on assumptions about income growth, the future path of energy prices and possible future policy delivery.

Methodology

The projection model is based on data from the 2010 EHS, which is the latest available data set and is the basis for the 2012 official fuel poverty statistics. It provides information on both the dwelling's physical characteristics and the household characteristics such as current income, energy costs, housing costs and the number of occupants. The information obtained through the survey thus provides an accurate picture of the type and condition of housing in England and the people living in those houses.

Future projections of fuel poverty are primarily based on the estimated change in household required energy costs due to government policies – e.g. the installation of energy efficiency measures or direct energy bill support. These estimates are then combined with assumptions about the future level of energy prices and incomes to estimate the level of fuel poverty at a particular point in time. It is important to remember that fuel poverty is concerned with the required level of energy to achieve a reasonable level of warmth for a household, and not the actual quantity of energy used at any one time. The key outputs of the projections model are the following: (a) the number of households in fuel poverty; (b) the aggregate fuel poverty gap; (c) the average SAP score for those in fuel poverty; and (d) the number of households living in fuel poverty below a specified SAP threshold. The broad structure of the model is shown in Figure 4.

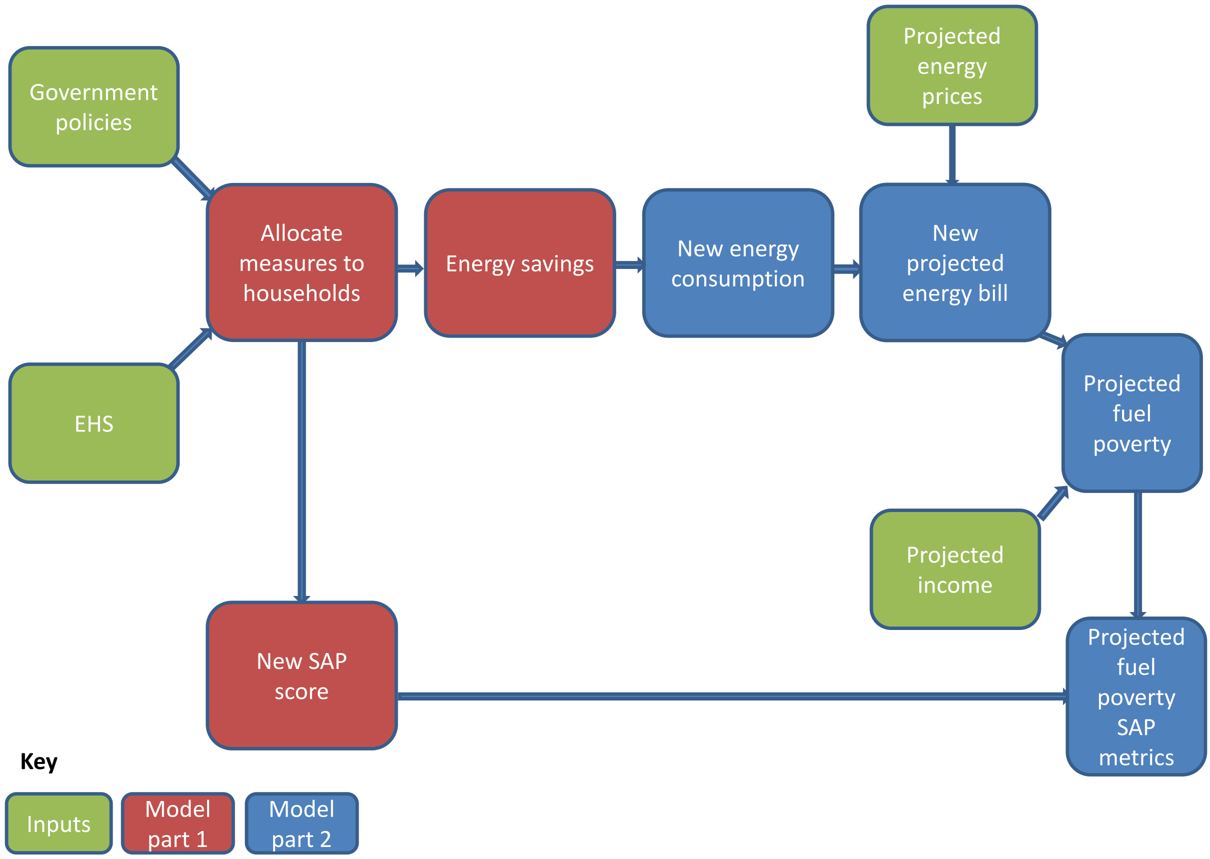


Figure 4: Summary of fuel poverty projections model methodology

Inputs

Making projections of fuel poverty means having to make assumptions about the future path of incomes and energy prices as well as the impact of Government policies that impact on the fuel poor (both in terms of what is delivered and which households are likely to receive support). The assumptions that underpin the projections set out in this Section are set out below.

Impact of Government Policies

The Government's energy and climate change policy package reduces energy costs for those households that receive support – which is mainly through energy efficiency measures and/or direct energy bill support. The projections in this document make assumptions about the future shape and direction of energy and climate change policies. As decisions on most future policies have yet to be taken, we should consider these projections as *illustrations* of how the level of fuel poverty could evolve over time.

For policies that have delivered measures to date, such as the Carbon Emissions Reduction Target, we have observed delivery statistics for the major energy efficiency installations.[12] For policies which will deliver measures in the future, we make use of projected installation patterns for each of the major measures which we take from the most recently published policy impact assessments. See Table 17, Table 18 and Table 19 for details of the measures estimated to be delivered under these policies and the relevant sources.

Many of the policies described below deliver measures to households across Great Britain. For the purpose of this analysis, the numbers of measures delivered in England (which is the relevant consideration from the perspective of projecting fuel poverty) is downscaled from the original figures in proportion to the number households in Great Britain located in England (which is around 86%). Naturally, the actual delivery pattern of planned policies may be different to what is set out here. Table 17 also sets out the details of the small number of measures that we would be expected to be delivered in the absence of policies. These are set out in the ‘no policies’ baseline. Most of the measures set out below are assumed to be delivered between 2010 and 2022, except for ‘carbon plan’ measures which are assumed to be delivered between 2022 and 2027. We have projected out to these two time frames because they are in line with the government’s carbon budget timeframes.

Table 20 sets out assumptions adopted that are not taken from policy IAs.

Table 17: Estimated uptake of insulation and heating measures (‘000s) from government policies in England, from 2010 onward

Policy	Loft	CWI	SWI	Replacement Boiler	Central Heating*	Source:
‘No policies’ baseline	267	356	6	0	0	Green Deal & ECO Final IA[13]
Warm front	9	21	0	117	28	Warm Front Annual Report 2010/11[14] and WF IA[15]

[12] Data on the actual measures delivered during 2012 Q4 (CERT) and 2012 Q3 – Q4 (CESP) were not available at the time that this analysis was undertaken. We have therefore projected forward delivery from these policies over these time periods, which may be different to actual reported delivery reported by Ofgem in May 2013.
[13] See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42984/5533-final-stage-impact-assessment-for-the-green-deal-a.pdf
[14] See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48168/2747-warm-front-annual-report-2010-2011.pdf
[15] See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42606/1442-ia-warm-front-eligibility.pdf

Policy	Loft	CWI	SWI	Replacement Boiler	Central Heating*	Source:
CERT	2,843	1,232	48	0	31	OFGEM CERT update (Issue 8 and 15)[16]
CESP	4	1	11	0	5	OFGEM 4th CESP report[17]
Green Deal and ECO: Carbon	894	2,155	818	0	0	GD & ECO Final IA
ECO: Affordable Warmth	529	90	1	780	57	GD & ECO Final IA
Carbon Plan: scenario 1	-	-	3,600	-	-	Based on HMG Carbon Plan[18]
Carbon Plan: scenario 3	-	-	1,284	-	-	Based on HMG Carbon Plan

***** Includes fuel switching under CERT and CESP. 'Loft' refers to Loft Insulation; 'CWI' refers to Cavity Wall Insulation; 'SWI' refers to Solid Wall Insulation.

[16] See: http://www.ofgem.gov.uk/Sustainability/Environment/EnergyEff/CU/Pages/CU.aspx
[17] See: http://www.ofgem.gov.uk/Sustainability/Environment/EnergyEff/cesp/Documents1/CESP%20Update%2006032012_final.pdf
[18] See: https://www.gov.uk/government/publications/the-carbon-plan-reducing-greenhouse-gas-emissions--2

Table 18: Estimated uptake of renewable energy measures (‘000s) from government policies in England, from 2010 onward

Policy	Biomass Boiler	Ground Source Heat Pump	Air Source Heat Pump	Solar Thermal	Source:
Renewable Heat Incentive (RHI)	55	52	237	8	RHI Consultation IA[19]
Carbon Plan: scenario 1	1,518	380	829	315	Based on HMG Carbon Plan
Carbon Plan: scenario 3	1,518	380	829	315	Based on HMG DECC Carbon Plan

Table 19: Estimated uptake of non-energy efficiency government policies (‘000s) in England, from 2010 onward

Policy	What is delivered?	How many household receive support (000)	Source:
Feed in Tariffs	Solar PV	2,004	FiT IA[20]
Warm Home Discount	Energy Bill Rebates	1,712 pa	WHD Impact Assessment[21]
Building regulations	Condensing boilers	10,222	Inferred from English House Condition Survey 1996 – 2007 and EHS 2008 - 2010

[19] See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/66156/RHI_domestic_scheme_-_impact_assessment.pdf
[20] See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/43080/5391-impact-assessment-government-response-to-consulta.pdf
[21] See: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42595/1308-warm-home-disc-impact-assessment.pdf

Table 20: Additional policy assumptions

Type of Assumption	Assumption adopted	Justification
Distribution of measures in any scenario	Distributed at random through micro-simulation model after taking account of policy eligibility criteria and the physical characteristics of households (e.g. SWI can only go to households with solid walls and AW measures can only go to those on qualifying benefits).	No information exists, to our knowledge, showing measures delivered are skewed to certain house types. For the Fuel Poverty Strategy we will explore whether there is a correlation between income and take-up of certain measures and use this to inform take-up in our scenarios.
Measures delivered between 2022 and 2027 in the no policy scenario	We assume no measures are delivered between 2022 and 2027 for the no policy scenario.	This is a simplifying assumption which we may return to for our Fuel Poverty Strategy document. However measures delivered in the absence of policies make up only 4% of measures delivered in 2022. Therefore this assumption is unlikely to have a large effect. Moreover we would expect this baseline figure to reduce as the potential for cheaper measures to be installed reduce.
Boiler upgrade in the absence of policies	We assume no improvement in boiler efficiency in the absence of policies, in particular building regulations. Therefore we assume people replace inefficient boilers with inefficient boilers.	Whilst this is a simplistic assumption, it seems reasonable given very small quantities of condensing boilers were sold before building regulations made it mandatory.

Underlying change in housing stack from new build and demolition of old ones	This is not taken into account in our model.	This is a simplifying assumption. However we will consider integrating evidence on this issue in our model for the Fuel Poverty Strategy.

All DECC policies that impact fuel poverty, as measured in the Fuel Poverty Methodology Handbook, have been included in this analysis[22]. See Section Five of this analytical annex ('Policies included in the FP-MACC baseline') for a description of what these are.

It is important to note that products policy has not been included because the Fuel Poverty Methodology does not account for appliance efficiency when measuring demand for electricity. This methodology only takes account of household floor area and number of occupants. Therefore Smart Meters are also not taken into account given that methodology is not sensitive to their impacts.

Projections of energy prices

The changes in energy prices form the base year are a combination of observed changes from 2009 to 2011, and DECC's most recent projected changes in the price of gas, electricity and 'non-metered' fuels. Projections of metered fuels (gas and electricity) are taken from DECC's publication: 'Estimated impacts of energy and climate change policies on energy prices and bills'[23], while changes in all other fuel prices are taken from DECC's published fossil fuel price series.[24] The total percentage changes in all energy prices between 2010 – 2022 and 2010 – 2027 are outlined in Table 21.

Prices are projected to increase steadily in the medium term – driven primarily by a combination of fossil fuel prices, transmission and distribution costs but also due to the costs associated with Government policies. The price of other fuels (i.e. coal, heating oil & LPG) is assumed to track fossil fuel prices.

The application of observed price increases from 2009 to 2011 is consistent with the official DECC Fuel Poverty Methodology, in which differences in regional and payment type costs (e.g. direct debit vs. pre-payment meters) are recognised. When projecting from 2011 to 2027, year-on-year percentage increases in the price of each fuel are only available at the national average level. We therefore implicitly assume that while prices increase overall, regional differences in prices and the relative costs of each payment method (e.g. direct debit, standard credit or pre-payment meter) remain fixed at the level set out in the base data.

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[22] Available at: https://www.gov.uk/government/publications/fuel-poverty-methodology-handbook
[23] See: https://www.gov.uk/government/publications/estimated-impacts-of-energy-and-climate-change-policies-on-energy-prices-and-bills
[24] See: https://www.gov.uk/government/policies/using-evidence-and-analysis-to-inform-energy-and-climate-change-policies/supporting-pages/policy-appraisal

Table 21: Estimated total percentage changes in energy prices

	2010 – 2022			2010 - 2027			
Fuel	High	Med	Low	High	Med	Low	Source[25]
Gas (without policies)	73%	38%	4%	76%	41%	7%	DECC Prices and Bills Publication
Gas (with policies)	73%	40%	6%	68%	35%	2%	DECC Prices and Bills Publication
Electricity (without policies)	48%	26%	4%	47%	26%	6%	DECC Prices and Bills Publication
Electricity (with policies)	68%	51%	37%	67%	56%	46%	DECC Prices and Bills Publication
Burning Oil	71%	41%	7%	102%	50%	-2%	HMG IAG Guidance
Solid Fuel	18%	-3%	-22%	26%	-3%	-22%	HMG IAG Guidance

Projections of incomes

Income projections are estimated by applying percentage changes in disposable income to the level of income in the base year, subtracting housing costs (to convert it to an 'After Housing Cost' value) and then equivalising to take account of the difference in household sizes.[26] Housing costs are netted from projections of real disposable income. Housing costs are rent and mortgage payments, which are stated in the base dataset and are assumed to remain constant in real terms over time (thus they are linked to the Consumer Price Index (CPI)).

Projecting disposable income involves combining information on the different types of household income, such as earnings, benefits and savings, and applying the

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[25] The 'with policies' and 'without policies' gas and electricity price series are sourced from DECC (2013) *Estimated impacts of energy and climate change policies on energy prices and bills*, available at: https://www.gov.uk/government/publications/estimated-impacts-of-energy-and-climate-change-policies-on-energy-prices-and-bills; the price series for burning oil and solid fuel are sourced from the Interdepartmental Analysts' Group guidance (published October 2012), available at: https://www.gov.uk/government/policies/using-evidence-and-analysis-to-inform-energy-and-climate-change-policies/supporting-pages/policy-appraisal

[26] See: http://www.oecd.org/social/family/35411111.pdf

relevant rates of change to them. These rates of changes are applied to the different components of income (from the EHS 2010 base data set) and then converted to real values (i.e. net of inflation).

A summary of the different income types, the source of their rates of projection and how they are transformed to real values is shown in Table 22.

The total percentage changes in income between 2010 – 2022 and 2010 – 2027 are outlined in Table 23.

Table 22: uprating the different components of income

Type	Method of projection	Method of adjusting for inflation
Earnings	Percentage change in nominal earnings from OBR (2013)[27]	Using GDP deflator series published by HM Treasury[28]
Investment and savings	The percentage change in real GDP from OBR (2013) is applied to both income and savings. This is because investments are likely to reflect the overall performance of the economy and no projections of the Bank of England Base Rate exist to estimate the likely performance of savings.	OBR projections already adjusted for inflation
Other private income	These include a wide range of relatively small income sources e.g. cash gifts from other family members. These are assumed to not change in real terms over time	Linked to Consumer Price Index
Benefits (including housing related) and tax credits	These are assumed to not change in real terms over time	Linked to Consumer Price Index

[27] See: Office for Budget Responsibility. (2013). *Outlook Report*. Available at: http://budgetresponsibility.independent.gov.uk/economic-and-fiscal-outlook-march-2013/
[28] See: http://www.hm-treasury.gov.uk/data_gdp_fig.htm

Table 23: Estimated total percentage changes in incomes

Income scalar	2010 – 2022			2010 - 2027			
	High	Med	Low	High	Med	Low	Source
Real GDP	83%	28%	-3%	191%	60%	-3%	OBR
Real Earnings	64%	10%	-14%	152%	24%	-18%	OBR

Modelling Impacts on Fuel Poverty

There are two parts to the projection model. The first part is a 'micro-simulation' model, which is used to allocate –measures to households (based on the policy assumptions highlighted above). The second part of the model is excel-based. This model calculates each household's energy consumption in the year under consideration (based on their initial energy consumption, reported in EHS 2010 and the 'energy savings factor' – that is, the change in energy requirement that results from the measures that are delivered) and combines this with the projected inputs of energy prices and income to calculate fuel poverty.

Part one: micro simulation model

The micro-simulation model (which is run in SAS) is used to allocate energy efficiency and heating measures, bill rebates and renewable technologies to households in the EHS dataset.

The policy inputs specify the number and type of measures that are installed through each policy as well as the types of households that can receive measures (e.g., measures that are installed through Affordable Warmth can only go to households that are in receipt of one of the qualifying benefits). There are also physical constraints to the up-take of measures – e.g., cavity wall insulation can only be installed in a dwelling with an unfilled cavity.

Each household that is allocated a measure realises an associated reduction in their kilowatt hour (kWh) energy consumption. The amount of energy saved depends on the type of measure installed and the property type in which it is installed. The property characteristics which determine the energy saving are: build type (e.g. end terrace, flat, etc.), depth of roof insulation, dwelling age, boiler age, water heating source, main heating fuel and main water heating fuel. These energy saving factors are provided by the Building Research Establishment (BRE) and are based on the BREDEM model.

There are different energy saving factors for different fuel types and fuel use. The fuels included are gas, electric, oil, solid fuel, biomass and the uses are heating, water, cooking and lighting. The savings are broken down in this way because some measures only impact on certain energy types, some increase one element of a household's energy bill and reduce another and others necessitate a complete change of fuel. For example:

- Where a gas centrally-heated home is allocated cavity wall insulation, it will see a reduction in kWh gas consumption for gas space heating but no reduction in the energy required for water, cooking and lighting;

- The installation of a biomass boiler means household gas consumption for heating is reduced to zero, but consumption for heating from biomass increases.

The impact of policies also leads to an estimated change in households SAP values. The impact policies have on SAP is also provided by BRE and is, again, based on the BREDEM model.

For each projection scenario, the micro-simulation model is run 100 times. A representative iteration is then chosen by looking at the iteration that gives an 'average' saving impact or distribution. This representative run is then used as the input for the excel-based model.

Part two: calculating fuel poverty

The original energy consumption for each household (by fuel type and use) from the EHS 2010 is then augmented using the energy saving factors (based on the outputs from the micro-simulation model) to create a new energy consumption value (also by fuel type and use). Current prices are applied to the new consumption to create a new energy bill.

The energy bill and income for each household is then up-rated to the target year (i.e. the year that we are projecting to) using the methodology described above. Finally, household incomes are adjusted to reflect any additional income from feed in tariffs and/or RHI tariff payments, and the final energy bill is calculated by reflecting the impact of Warm Home Discount rebates and Green Deal charges (whether a household receives any of these policies is taken from the micro simulation results).

A new energy threshold and median income can then be calculated so that it is possible to calculate the level of fuel poverty in the target year.

Households SAP ratings after policies have been introduced can then also be used to estimate what the average SAP of those people in fuel poverty are or how many people in fuel poverty have a SAP score of below a certain threshold.

Results

The 2022 and 2027 projection results for a number of different illustrative policy scenarios are set out in the tables below. The policy scenarios we have modelled are:

a) No policies baseline: no policy impacts are modelled. Projections reflect just the impact of changes in process and incomes;

b) Carbon Plan scenario 1: assumes that all of the policies in Table 17, Table 18 and Table 19 are implemented to 2022. Post 2022 assumes that policies deliver the measures in carbon plan scenario 1.

c) Carbon Plan scenario 3: assumes that all of the policies in Table 17, Table 18 and Table 19 are implemented to 2022. Post 2022 assumes that policies deliver the measures in carbon plan scenario 3.

All of the scenarios are modelled against a range of different energy prices and income assumptions.

Table 24: projections of fuel poverty and fuel poverty gap (central income scenario, varying price scenarios)

Year	2010	2022		2027		
Policy scenario	-	No policies	With policies	No policies	CP Scen. 1	CP Scen. 3
Central Fossil Fuel Prices						
No of LIHC households (000)	2,474	2,673	2,513	2,674	2,457	2,483
Aggregate FP gap (£mn)	1,000	1,500	1,177	1,546	1,065	1,124
Average FP gap (£)	405	561	469	578	433	453
Low Fossil Fuel Prices						
No of LIHC households (000)	2,474	2,538	2,400	2,585	2,403	2,394
Aggregate FP gap (£mn)	1,000	1,195	958	1,225	925	939
Average FP gap (£)	405	471	399	474	385	392
High Fossil Fuel Prices						
No of LIHC households (000)	2,474	2,800	2,624	2,771	2,542	2,573
Aggregate FP gap (£mn)	1,000	1,856	1,427	1,911	1,222	1,329
Average FP gap (£)	405	663	544	690	481	516

Table 25: projections of fuel poverty and fuel poverty gap (central price scenario, varying income scenarios)

Year	2010	2022		2027		
Policy scenario	-	No policies	With policies	No policies	CP Scen. 1	CP Scen. 3
Central Income Growth						
No of LIHC households (000)	2,474	2,673	2,513	2,674	2,457	2,483
Aggregate FP gap (£mn)	1,000	1,500	1,177	1,546	1,065	1,124
Average FP gap (£)	405	561	469	578	433	453
Low Income Growth						
No of LIHC households (000)	2,474	2,690	2,596	2,745	2,526	2,574
Aggregate FP gap (£mn)	1,000	1,526	1,196	1,569	1,122	1,163
Average FP gap (£)	405	567	461	572	444	452
High Income Growth						
No of LIHC households (000)	2,474	2,904	2,642	2,771	2,542	2,573
Aggregate FP gap (£mn)	1,000	1,856	1,427	1,911	1,222	1,329
Average FP gap (£)	405	663	544	690	481	516

Table 26: projections of average SAP amongst fuel poor households (central prices and incomes scenario)

Year	2010	2022		2027		
Policy scenario	-	No policies	With policies	No policies	CP Scen. 1	CP Scen. 3
Average SAP rating of LIHC households	46.5	46.4	55.0	46.5	57.6	56.0
Number of LIHC Households with a SAP Rating <55 (000)	1,813	1,947	975	1,942	720	857

Section Five: The fuel poverty marginal alleviation cost curve

Support can be given to fuel poor households in a range of different ways. Opportunities to provide different forms of support vary, and the costs and benefits of alternative interventions can also fall within wide ranges. As in all areas of policy, the available resources to achieve fuel poverty objectives are limited. Given this, it is imperative to consider which fuel poverty interventions are most effective and have the greatest impact.

In the new framework document we have proposed a new form for the fuel poverty target for England – based on improving the level of energy efficiency amongst fuel poor households.

Upgrading the energy efficiency of fuel poor homes can be undertaken in a growing number of ways. Choosing the right mix of interventions, and determining the right time to deploy each intervention, requires a comprehensive and robust assessment of the available options, the impact they could have on making progress towards any new target, and the relative level of resources they would require to achieve that level of progress. In doing so we will be able to broadly determine the most cost-effective mix of interventions over time to make progress towards any proposed target.

Determining cost-effectiveness – Marginal Abatement Cost Curves

Setting out and estimating cost-effectiveness at different points in time is an established approach that already underpins a number of areas of policy. The most familiar of these is climate change mitigation policy. The approach there involves:

- <u>establishing a 'progress metric</u>' (e.g. mega-tonnes of greenhouse gas emissions (MtCO_2e));

- <u>assessing how a range of interventions would score against that progress metric</u> (e.g. insulating all domestic homes could generate savings ("progress") of *X* MtCO_2e); and

- <u>establishing 'a cost metric' – the cost of achieving that progress</u> (e.g. to insulate all domestic homes would cost £*Y* bn). The cost is typically calculated as a 'net social cost', whereby the costs and benefits of undertaking the intervention are estimated, and if the benefits outweigh the costs then the 'net social cost' is negative – i.e. the intervention makes progress against the metric and results in a net benefit to society.

The interventions can then be ranked in terms of how they score against the progress metric, factoring in how much it would cost per unit to achieve that progress. This effectively provides a cost-effective ordering of interventions and, by implication, a set of the most cost effective interventions with which to achieve a certain level of progress (which could also be a target) at that point in time.

In climate change mitigation policy, the cost-effective ordering of interventions is depicted in a 'Marginal Abatement Cost Curve' (MACC), as it ranks interventions based on their cost-effectiveness for abating greenhouse gas emissions. The MACC allows decision makers to assess how much progress is already being made and subsequently consider what it would cost (or save) to make more (or less) progress from that point – the cost at the margin (Figure 5).

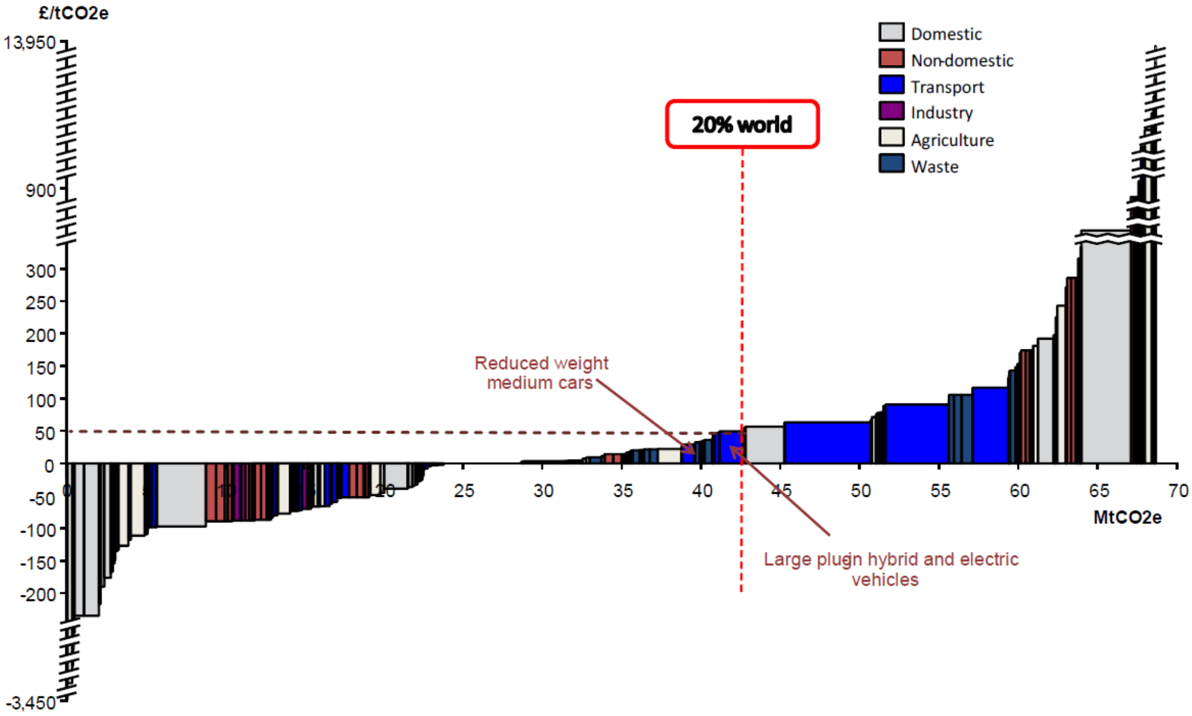

Figure 5: An example greenhouse gas MACC for the UK in 2020[29]

Fuel Poverty Marginal Alleviation Cost Curves

The same approach to constructing MACCs for climate change or overall energy efficiency policy can also be applied to fuel poverty, providing: we have a progress metric; a range of interventions that we know would score against that metric; and are able to consistently estimate the net social costs of those interventions. Doing so enables us to construct FP-MACCs to assess, at different points in time, what the most cost-effective interventions are and how much progress these interventions could potentially make towards fuel poverty objectives.

It is important to state that all the following analysis focuses on the construction of technical MACCs. This means that our estimates of the potential for interventions

[29] Source: DECC (2009). Carbon Valuation in UK Policy Appraisal: A Revised Approach. See: https://www.gov.uk/carbon-valuation

are made on the basis of technical feasibility and do not account for the willingness of households to receive interventions or the delivery mechanism for that intervention. This means that all interventions are considered independently of any current policy approach to delivery. For example, if considering the potential and costs associated with renewable heating, we focus on the capital, operating and hidden costs of the intervention only, and not any subsidy requirements to incentivise households to take up the measure. This ensures that the assessment of cost-effectiveness is not in any way biased by the strengths or weaknesses of current delivery approaches for certain interventions.

It is also important to note that the fuel poverty MACCs are not additive in the same way that some carbon MACCs are. As shown in Figure 5 the carbon MACC allows you to see the effects of accumulated mitigation action and thus assess the costs to society of meeting a certain target. You cannot see the costs of achieving certain targets from the fuel poverty MACCs because the impacts of measures are not cumulative at present. They therefore represent action from measures delivered in isolation. The fuel poverty strategy will aim to analyse how these measures interact together so that we can offer an additive MACC.

Methodology for creating FP-MACCs

The key considerations in creating an FP-MACC are:

a) The progress and cost metrics;
b) The timeframe – MACCs are always a snapshot in time, so choices need to be made in relation to which years to consider;
c) The baseline – the type and scope of interventions feasible at any point in time is dependent on the impact that existing policies and 'business as usual' behaviour have had to date in the timeframe chosen;
d) The range of interventions considered for analysis and which households are considered eligible / are targeted for measures;
e) The technical potential for and impact of different interventions on the progress metric; and
f) The approach to consistently estimating the costs and benefits of interventions.

The following sections discuss each of these considerations.

Progress and Cost metrics

There are a number of relevant progress metrics that could be used in an FP-MACC. The foremost of these are:

- The Fuel Poverty Gap – progress would be measured in terms of the estimated reduction in the aggregate fuel poverty gap (in £m) as a result of each alternative intervention; and
- The energy efficiency of fuel poor households.

To illustrate the methodology for creating an FP-MACC, here we use a progress metric of the energy efficiency standard of fuel poor households – specifically the number of fuel poor households with a SAP rating below 55.

Selecting an appropriate cost metric is relatively straight forward given standard Government practice for assessing social costs and benefits when making policy decisions. Mirroring the approaches taken to greenhouse gas and energy efficiency MACCs, here we adopt the *net social cost* of undertaking different interventions as our cost metric, where positive Net Present Values (i.e. where the social benefits outweigh the social costs) are expressed as *negative costs*. For example, if upgrading a household's boiler generates net social benefits of £2,000, this *benefit* is expressed in the form of a *cost* of -£2,000.

These two metrics can then be combined as demonstrated in Table 27. Column [1] shows the cumulative reduction in the number of fuel poor households with a SAP rating less than 55 that could be potentially be achieved through the intervention; column [2] shows the reduction that each illustrative *individual* intervention could achieve; column [3] shows the net social cost of the intervention; and column [4] the cost per household moved above the efficiency threshold.

Table 27: Illustrative combination of Progress and Cost metrics

	Cumulative aggregate reduction in the number of FP households with SAP < 55	Reduction in the number of FP households with SAP < 55 from intervention	Net social cost (£bn)	Net social cost / household
Intervention	[1]	[2]	[3]	[4]
Start point	0	0	0	([3] ÷ [2])
Intervention A	200	200	- 4.0	-£20
Intervention B	600	400	- 6.0	-£15
Intervention C	700	100	+ 1.0	+£10
Intervention D	1,100	500	+ 5.0	+£15

Figure 6 translates this table into an illustrative FP-MACC. This shows us that Interventions A and B can make significant potential progress and implementing them would generate positive benefits (negative costs) to society at the same time.

Intervention D, meanwhile, has the potential to make the most progress of any individual intervention, but it would be a costly way of doing so because – independent of the aim to reduce the number of households with a SAP less than 55 – the costs of intervening outweigh the benefits of doing so.

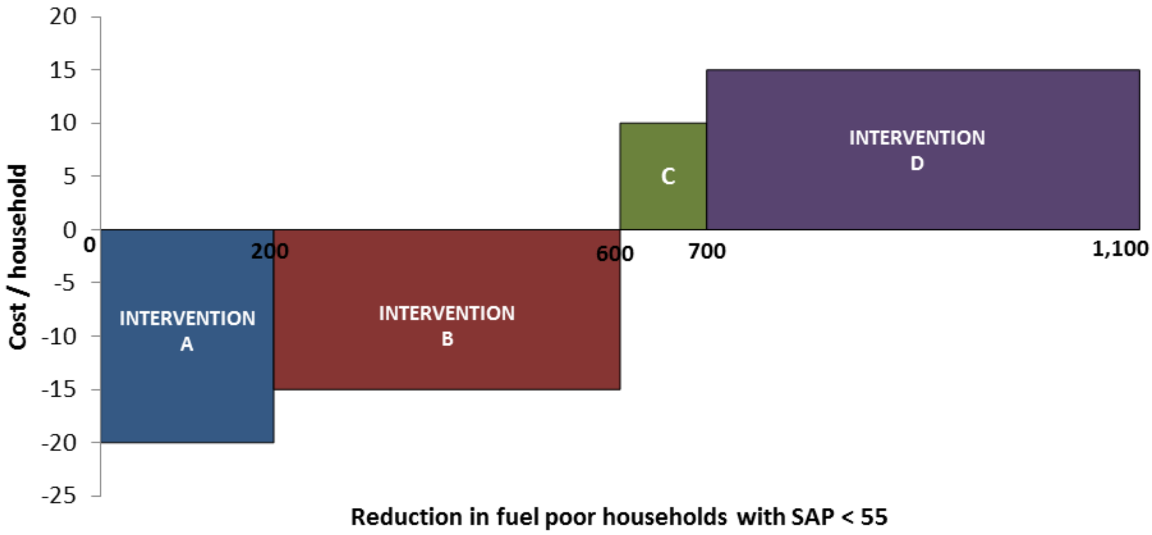

Figure 6: Illustrative combination of Progress and Cost metrics in an FP-MACC

Timeframe

A MACC is a snapshot in time, typically showing a range of interventions that could achieve different levels of progress in a certain year, compared to a baseline for that year. As a result, it is particularly useful for setting out which interventions could achieve a certain level of progress in that year at lowest cost. As a result, MACCs naturally lend themselves to situations where there is an objective or target for a certain level of progress by a certain time.

We have therefore constructed FP-MACCs for the following timeframes: 2015, 2022 and 2027.

Baseline

The appropriate baseline for estimating an FP-MACC is heavily linked to the policy question being asked. For example, if the question were relating to how much further progress could be made in addition to current and future policy intentions, then all current and estimated future policy impacts should be in the baseline. Alternatively, if the question relates to what is an optimal mix of interventions in order to inform and shape future policy, then the baseline should only include those policies currently in place and should ignore policies that are yet to come into force.

The use of FP-MACCs in this strategic framework is to evidence which types of measure offer the greatest potential to make cost-effective progress towards a potential target. This means that when projecting a baseline of what our progress metric might look like in 2015, 2022 and 2027, we take account of the impact of current policies and what they deliver until the end of the current Spending Review period before considering which interventions could make further progress.

It is important to note that the projections presented in Section Four show the impact of policies on fuel poverty out to 2022 and 2027, whereas the policy baseline for these MACCs extends to 2015 only.

Policies included in the FP-MACC baseline

The policies and interventions considered here only relate to those that would affect required energy needs as calculated in line with the *Fuel Poverty Methodology Handbook*.[30] This broadly translates into any measure that affects the efficiency of a domestic dwelling's building fabric and its heating system, or direct impacts on bills via price increases/decreases or bill discounts. Policies that affect energy use through the use of appliances, such as some Products Policies, are not included. This is because the Fuel Poverty Methodology calculates energy use for lights and appliances via an algorithm based on the size of a dwelling and the number of inhabitants, not the number of appliances in the home and their efficiency.[31] Similarly, any policies that drive behaviour change of *actual* energy use, but do not affect *required* energy use, are excluded as they would not have any direct impact on our proposed progress metrics. This is not to say that there is no merit in these types of interventions in fuel poor households, but simply that they are not included in this analysis. We also exclude interventions that require a specific number of households within a certain geographical area to take up a measure in order to make it viable, such as district heating. This is primarily because the evidence suggests that fuel poor households do not tend to be clustered in loosely defined areas. While many fuel poor households could potentially benefit from such interventions, we do not include them as fuel poverty-specific interventions.

At present, the underlying fuel poverty dataset on which an FP-MACC is based is 2010. As such, projecting a baseline forward to 2027 means simulating domestic sector energy policy activity undertaken between 2010 and 2015. The policies simulated (also depicted in Figure 7) are:

- Warm Front (ended 2013)
- CERT (ended 2012)
- CESP (ended 2012)
- Green Deal and ECO (2013 – 2015)
- Feed-in-Tariffs (2010 – 2015)
- Renewable Heat Incentive (2014 – 2015)

[30] Available at: https://www.gov.uk/government/publications/fuel-poverty-methodology-handbook
[31] This means that if the efficiency of domestic appliances improves from one year to the next, this would not show up in modelled energy needs for fuel poverty calculations. While this is an issue that should be considered for future revisions of the Fuel Poverty Methodology, for the purposes of an FP-MACC it is important to reflect the impact of interventions in the way that the current Fuel Poverty Methodology would. We therefore ignore products policies at present.

- Warm Home Discount (2011-2015) and
- the natural replacement of non-condensing gas and oil boilers with new condensing boilers as a result of Building Regulations.

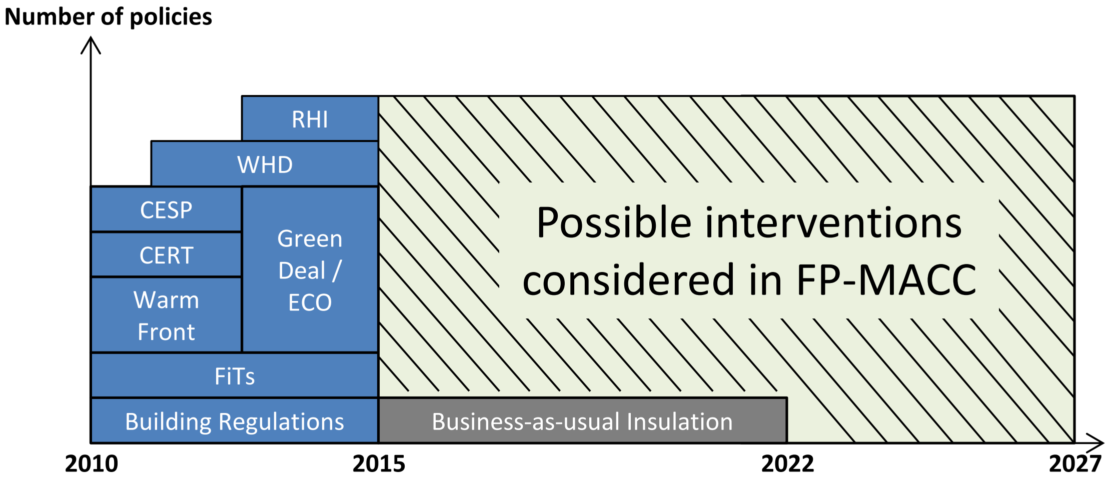

Figure 7: Illustration of policies to include in the FP-MACC baseline

Our illustrative Business-As-Usual (BAU) scenario therefore assumes that from 2015 onwards no energy and climate change policies continue to deliver. It is important to note that this is purely an assumption in order for technical potential to be analysed here independently of policy impacts post-2015 – this does not alter any announced policy or commitments.

This baseline assumption would mean that some activity that is currently projected to be delivered by current policies that continue beyond the end of the Spending Review period is not included in the BAU scenario. For example, the insulation projected to be delivered under Green Deal and ECO) would be counted among the pool of *potential* interventions considered in the FP-MACC.

The baseline does not assume, however, that all energy efficiency activity ceases beyond 2015. While policy is the principal driver for domestic energy efficiency measures, and while t is reasonable to assume that negligible levels of certain more expensive measures would be delivered in the absence of policies, it is also likely that some measures – such as low-cost insulation – would be installed in the absence of policies, albeit at much lower volumes. The analysis underlying the Green Deal and ECO Final Impact Assessment[32] included a “BAU” scenario whereby take-up of cavity wall insulation, loft top-up insulation and solid wall insulation were modelled from 2013-2022 in the absence of any domestic insulation retrofit policy. We have therefore included this uptake as part of the baseline covering 2015 to 2022 and onwards. The baseline and policy scenario projections of changes in the progress metrics are undertaken using the Fuel Poverty Projections Model (see Section Four for more details).

[32] Available at: https://www.gov.uk/government/consultations/the-green-deal-and-energy-company-obligation

Range of interventions and targeting

There are a range of interventions that could be considered in the FP-MACC, from relatively minor measures such as hot water tank jackets, to large scale developments like gas-grid extension or communal heating. For practical reasons and also ease of interpretation of a MACC it is necessary to focus only on major measures. By this we mean that it is sensible to focus only on those measures that:

- Make a significant impact on the progress metric[33];
- Are feasible interventions that can be directed at individual households and are not conditional on mass roll-out[34];
- It is technically possible to model through cost-benefit methodologies.

Table 28 lists the measures that are judged to fit these criteria. Any of these technologies that would lead to a *negative impact* on household energy costs – for example for some households replacing a gas-fired boiler with an alternative that is more expensive to operate – will be excluded from the FP-MACC.

Table 28: Proposed list of interventions to be considered in the FP-MACC

Conventional Space Heating Measures	Renewable Space Heating Measures	Insulation Measures	Other Interventions
Gas Central Heating	Air Source Heat Pump	Cavity Wall Insulation	Direct Energy Bill Discount[35]
Oil/LPG Central Heating	Ground Source Heat Pump	Loft Insulation	
Electric Central Heating	Biomass Boiler	Internal Solid Wall Insulation	
Condensing Gas Boiler Upgrade		External Solid Wall Insulation	

[33] In effect this means excluding minor measures like hot water tank jackets, as well as those that would not have an impact on modelled energy requirements as defined by the Fuel Poverty Methodology: for example A-rated refrigerators or behavioural measures like smart meters that do affect *actual* energy use, but do not affect *required* energy use – fuel poverty is defined on the basis of *required* energy use.

[34] While some fuel poor households are more highly concentrated in some regions than others, overall they do not tend to live in clearly defined areas and their characteristics can vary significantly. This makes it important to primarily consider for specific fuel poverty interventions only those measures that can be targeted at individual fuel poor households (e.g. individual heating systems) rather mass roll out technologies (such as new district heating) that require more than a single household to take up in order to make it viable.

[35] In order to build energy bill rebates into the MACC we have adjusted the SAP related household energy costs for recipient households – see Section 7 for more details.

Conventional Space Heating Measures	Renewable Space Heating Measures	Insulation Measures	Other Interventions
Condensing Oil Boiler Upgrade			

We will continue to develop this analysis over time and, where possible, we will build in additional measures.

Potential and the impact of interventions on the progress metric

Technical potential to undertake different types of interventions are drawn from the Fuel Poverty Dataset 2010, which itself is drawn from the EHS 2010. For some interventions, such as insulation and conventional heating, the survey data show which households have the potential to have those measures installed. For others, such as biomass boilers, judgements must be made about which households are likely to be technically able to have them installed.

The 2010 EHS data provide a snapshot of the potential to undertake different interventions in that year, but we know that policies have delivered measures since 2010 and anticipate that more measures will be delivered between now and the end of 2015 – the year we assume policies cease delivering for our baseline. In order to estimate the impact of policies on energy efficiency ratings of households up to 2015, we first micro-simulate the installation of measures under each policy, drawing on reported data where they exist and published projections from Impact Assessments elsewhere. Table 29 lists the assumptions made on household eligibility for different interventions. At present we do not place constraints on interventions based on currently known supply constraints. In reality, certain technologies may not be able to be deployed easily at the scale indicated in these FP-MACCs. However, as the purpose at present is to identify the technologies which could *technically* be deployed (and their relative cost-effectiveness), we do not make assumptions about supply constraints at present. We will consider supply constraints further for the Fuel Poverty Strategy.

Table 29: Technical potential assumptions

Intervention	Technical Potential Listed in EHS 2010?	Assumptions made about household eligibility for measure	Policies projected to affect potential between 2010 and 2015
Cavity Wall Insulation	Yes	If listed in EHS as not having an insulated cavity wall *and* built pre-1995*	• CERT • CESP • Warm Front • Green Deal/ECO

Intervention	Technical Potential Listed in EHS 2010?	Assumptions made about household eligibility for measure	Policies projected to affect potential between 2010 and 2015
Loft Insulation	Yes	If listed in EHS as having less than 150mm of insulation	• CERT • CESP • Warm Front • Green Deal/ECO
Solid Wall Insulation	Yes	If listed in EHS as having a solid wall and no insulation	• CERT • CESP • Green Deal/ECO
Central Heating	Yes	If listed in EHS as not having a central heating system	• Warm Front • Green Deal/ECO • Building Regulations
Condensing Boilers	Yes	If listed in EHS as not having a condensing boiler	• Warm Front • CESP • CERT • Green Deal/ECO • Building Regulations
Air Source Heat Pumps	No	All households eligible	• Renewable Heat Incentive
Ground Source Heat Pumps	No	If listed in EHS as not being a flat and being in a rural area	• CERT • Renewable Heat Incentive
Biomass Boilers	No	If listed in EHS as not being a flat and being in a rural area	• Renewable Heat Incentive
Direct Energy Bill Discount	No	All households eligible	Warm Home Discount – does not have any lasting impact on future years post-2015

* The EHS lists some post-1995 dwellings as having not having insulated cavity walls as a result of misidentification. Building regulations required all post-1995 new builds to have insulated cavity walls.

For some measures where the EHS does not state whether a household is eligible for a measure, our current assumptions are broad. For example, households without any outdoor space are unlikely to be candidates for a Ground Source Heat Pump. We are developing our understanding of technical feasibility of interventions and intend to publish updated FP-MACCs using more detailed eligibility criteria alongside the future fuel poverty strategy. For the current analysis, we use the broad assumptions in Table 29 to illustrate the relative cost-effectiveness of different interventions only.

The impacts of different interventions in this FP-MACC are considered in isolation and are therefore non-additive. This is because the impact of each intervention on the progress metric is, in most cases, at least partly conditional on the interventions that have preceded it. For example, insulating the walls of ten homes that have a non-condensing boiler leads to a greater improvement in SAP than insulating the walls of ten otherwise identical homes that already have condensing boilers. This means that analysing the impact of each intervention on the progress metric in isolation results, in many cases, in not being able to simply add up the impact of each individual intervention to arrive at a target total.

Where an FP-MACC is being used to estimate a pathway to achieving a target, this 'non-additivity' of interventions could prove to be an issue. To be able to conclude that undertaking a set of interventions will generate a certain level of progress towards a target we need to be able to take the overlaps to be taken into account. We intend to construct 'additive FP-MACCs' that overcome this issue and publish them alongside the future Fuel Poverty Strategy.

Approach to consistently estimating the social costs and benefits of interventions – the cost metric

Estimating the social costs and benefits of each intervention considered in the FP-MACC enables us to estimate the net social cost of making progress – the cost metric. In order to make robust comparisons of net costs across a variety of interventions it is imperative to use consistent assumptions and data relating to the fuel poor households being targeted, and a consistent approach to estimating the costs and benefits of each intervention.

All the costs and benefits of interventions considered in the FP-MACC are estimated using approaches consistent with those used in Impact Assessments of current or committed policies that are delivering or will deliver those interventions. In terms of overall appraisal framework, all interventions considered in the FP-MACC are assessed using the HM Treasury *Green Book* methodology[36] and all energy and greenhouse gas changes are valued following the supplementary guidance on the *Valuation of energy use and greenhouse gas emissions*.[37] We have not applied equity weights to our estimates of NPV. If we were to do so, we would expect to see the net costs to society from these measures to decline given the benefits would be directed at those with low income. We will consider including the equity adjusted figures in our Fuel Poverty Strategy. In a carbon MACC, the NPV to society is net of the progress made on the x-axis i.e. abating carbon. Because we do not have a monetary value of reducing fuel poverty we are not able to do this.

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[36] Available at: https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent
[37] Available at: https://www.gov.uk/government/policies/using-evidence-and-analysis-to-inform-energy-and-climate-change-policies/supporting-pages/policy-appraisal

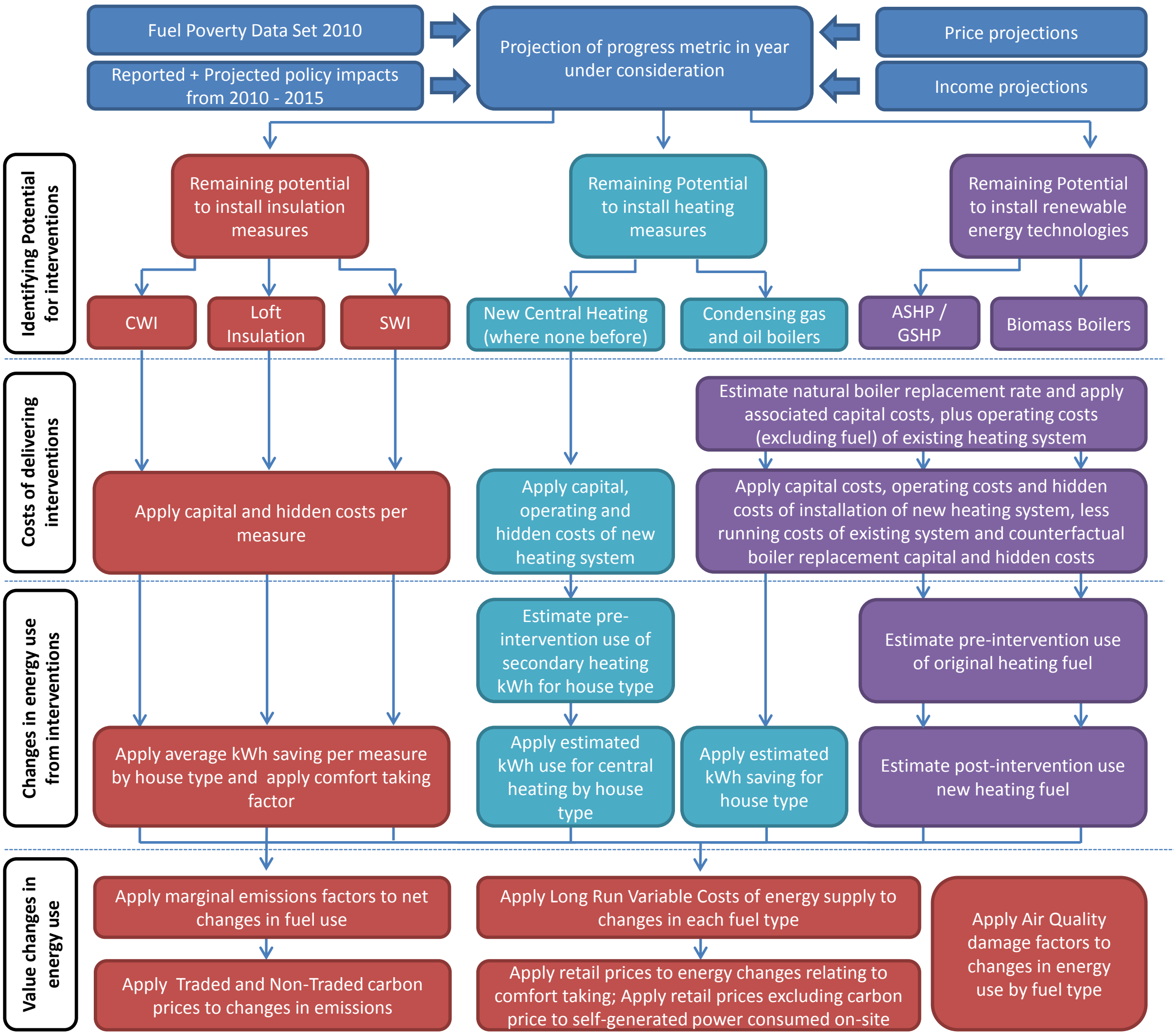

Figure 8: Overview of approach to estimating the social costs and benefits of interventions (excluding energy bill rebates)

Figure 8 provides an outline of the approach used for modelling interventions that directly affect energy use. Energy bill rebates follow a different approach which is set out below.

Key distinctions and adjustments

In carrying out the cost-benefit analysis of different interventions we distinguish between fuel poor households and adjust estimated energy usage / savings in four main ways:

1) Their main heating fuel type – mains gas, electricity, or 'other off-grid' where we use heating oil as a proxy for this whole group for reasons of sample sizes in the underlying data;

2) The type of dwelling – flat, semi-detached/end terrace house, mid-terrace house, detached house or bungalow. This enables us to map observed differences in energy use across different dwelling types from the National Energy Efficiency Data framework (NEED)[38] on to the estimated energy savings from each intervention. This is important given that LIHC households are not necessarily representative of the national housing stock: using estimates of average changes could potentially yield misleading results;
3) The size of dwelling – different types of dwelling can vary considerably by floor area. Therefore we also make adjustments to changes in energy use to reflect the average size of fuel poor homes *within* different house types, again using observed data from NEED.
4) The income grouping of the household – within dwellings of similar type and size, households on different incomes consume different amounts of energy. We therefore map patterns of energy use by income group from NEED on to fuel poor households and adjust their estimated energy usage in line with their income levels.

Among fuel poor households there is also variation in these four key factors. For example, those households in the most severe fuel poverty (as measured by the fuel poverty gap) tend to live in larger dwellings and have a higher concentration of off gas-grid heating fuels. We therefore segment the fuel poor population into the three ‘nests’:

1) The ‘Bottom Nest’ the 1/3 of fuel poor households in the most severe fuel poverty (as measured by the fuel poverty gap);
2) The ‘Top Nest’ – the 1/3 of fuel poor households with the smallest fuel poverty gaps; and
3) The ‘Middle Nest’ – the remaining 1/3 of fuel poor households.

Estimating the costs and benefits of insulation interventions

To estimate the net social cost of installing insulation, a projection is made of the remaining opportunities to install these measures after policies have delivered to 2015 (Table 30). The technical potential in each ‘nest’ varies over time, in small part due to a relatively small number of households taking up insulation after 2015 without policy incentives, but in the main due to the composition of households in each ‘nest’ changing over time in line with prices and incomes.

The estimated split in technical potential between lower cost ‘Easy to treat’ (ETT) Cavity Wall Insulation (CWI) and ‘Hard to treat’ (HTT) CWI is consistent with the

[38] For further details see: https://www.gov.uk/government/organisations/department-of-energy-climate-change/series/national-energy-efficiency-data-need-framework

approach used in the Green Deal and ECO Final Impact Assessment. This is also the case for the estimated split between the main types of solid walls.[39]

Table 30: Estimated technical potential for insulation measures in fuel poor households in England (net of baseline)

Insulation Measures	2015	2022	2027
Cavity Wall Insulation	**541,000**	**545,000**	**541,000**
- Bottom Nest	199,000	200,000	196,000
- Middle Nest	186,000	199,000	195,000
- Top Nest	156,000	156,000	149,000
Loft Insulation <150mm	**967,000**	**950,000**	**948,000**
- Bottom Nest	392,000	385,000	386,000
- Middle Nest	315,000	297,759	289,000
- Top Nest	260,000	267,000	273,000
Solid Wall Insulation	**1,180,000**	**1,190,000**	**1,167,000**
- Bottom Nest	539,000	533,000	531,000
- Middle Nest	342,000	347,000	338,000
- Top Nest	299,000	310,000	298,000

Source: English Housing Survey (2010), after impact of projected policy delivery to 2015

We then apply estimates of the capital and hidden costs of delivering these measures to derive an estimated total installation cost. These cost estimates are sourced from the final Green Deal and ECO impact assessment, and summarised in Table 31. It is estimated that the costs of Solid Wall Insulation will reduce by a total of 15% between 2013 and 2022, while the costs of the more established loft and cavity wall insulation are assumed to stay constant in real terms.

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[39] See Annex A of the Green Deal and ECO Final Impact Assessment for more details: https://www.gov.uk/government/consultations/the-green-deal-and-energy-company-obligation

Table 31: Average capital and hidden cost estimates for installing insulation measures

Measure	2015	2022	2027
Cavity Wall Insulation (ETT)			
- Capital Cost	£500	£500	£500
- Hidden Cost	£78	£78	£78
Cavity Wall Insulation (HTT)			
- Capital Cost	£1,875	£1,875	£1,875
- Hidden Cost	£78	£78	£78
Loft Insulation <150mm			
- Capital Cost	£300	£300	£300
- Hidden Cost	£103	£103	£103
Solid Wall Insulation (internal)*			
- Capital Cost	£5,612	£4,935	£4,935
- Hidden Cost	£4,937	£4,937	£4,937
Solid Wall Insulation (external)*			
- Capital Cost	£10,295	£9,052	£9,052
- Hidden Cost	£178	£178	£178

* Costs of internal and external SWI vary depends on the area of a dwelling's external wall. The example in this table is for a large semi-detached house / end-of-terrace.
Source: Green Deal and ECO Final Impact Assessment[40]

We then apply estimates of the average actual kWh energy saving that is achieved from the installation of these measures, which are sourced from the Green Deal and ECO Final Impact Assessment.[41] An example of the savings for a typical sized semi-detached gas-heated dwelling is set out in Table 32. Typical energy savings

[40] Available at: https://www.gov.uk/government/consultations/the-green-deal-and-energy-company-obligation

[41] The November 2012 report provides recent estimates of the kWh savings from major insulation measures. However, due to limited sample sizes relating to Solid Wall Insulation, the comparability of typical energy savings across all insulation measures is not yet sufficiently robust for policy analysis. As a result, we continue to use the savings estimates from the Green Deal and ECO Final Impact Assessment in this analysis.

from these measures are then adjusted to reflect the mix of dwellings, dwelling sizes, incomes and heating fuel mix of fuel poor households in each 'nest', to obtain an estimate of total changes in energy *from these interventions.*

Table 32: Estimated energy savings from insulation measures for a typical sized semi-detached, gas-heated house

Measure	Estimated kWh saving before comfort taking	Estimated kWh saving after 15% comfort taking
CWI	2,673	2,272
Loft Insulation*	499	424
SWI: Type I	6,150	5,227
SWI: Type II	5,494	4,670
SWI: Type III	3,789	3,221

* This is an illustrative top up from 100mm to 250mm, rather than an average energy saving.
Source: Green Deal and ECO Final Impact Assessment, Table 30[42]

The estimated benefit of saved energy resources is then valued by applying estimates of the Long Run Variable Cost of energy supply to the total changes in energy from each insulation intervention. The energy saving forgone in comfort taking[43] is valued using retail energy prices. Estimates of the changes in greenhouse gas emissions are derived by applying emissions factors to the kWh of each fuel type saved, and these are then valued using estimated carbon values from the IAG guidance. The benefits of improved Air Quality are also valued by applying (forgone) air quality damage estimates.

Estimating the costs and benefits of heating interventions

The approach to estimating the net social cost of heating interventions differs between upgrading to condensing gas or oil boilers, new central heating (moving from secondary heating), and renewable space heating technologies. For all heating interventions the valuation of changes in energy use, comfort taking, changes in emissions and air quality is undertaken in the same way as for insulation measures.

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[42] Available at: https://www.gov.uk/government/consultations/the-green-deal-and-energy-company-obligation

[43] Insulating a dwelling means that the same level of internal comfort can be achieved at a lower cost, and on average this lower cost leads to households opting to forgo some of the potential energy savings in favour of a warmer internal climate. This is termed 'comfort taking'.

Replacement boilers

Estimates of the number of non-condensing boilers in fuel poor households is made through a projection the remaining opportunities to install these measures after policies have delivered to 2015 (Table 33).

Table 33: Estimated potential to install condensing boilers in fuel poor households in England (net of baseline)

Measure	2015	2022	2027
Condensing Boilers	**1,463,000**	**1,451,000**	**1,431,000**
- Bottom Nest	535,000	497,000	496,000
- Middle Nest	492,000	512,000	496,000
- Top Nest	436,000	443,000	440,000

Source: EHS (2010), after impact of projected policy delivery to 2015

In estimating the capital and hidden costs of installing condensing boilers, it is important to consider the counterfactual, as in the absence of this intervention the majority of households would at some point in the future replace their existing boiler when it comes to the end of its natural life. This means for example, that for most households, intervening to upgrade to condensing boilers in 2015 would bring forward the costs to 2015 from a later date. The implication is that the *net* cost of installing condensing boilers in 2015, for example, is the difference between the cost of upgrading sooner rather than later. As we assume that, as a a mature technology, the capital costs stay constant in real terms, this means the *net capital cost* is the difference in discounted costs of installation only.

A further consideration in the counterfactual is timing of boiler replacements in the absence of policy. A boiler replacement represents a large upfront cost to households, in particular for those on low incomes, and all fuel poor households are on low incomes by definition. This means that when a fuel poor household's boiler comes to the end of its natural lifetime, in many cases it is not replaced straight away, and observations under recent policies such as Warm Front suggest that in these situations households sometimes go for a significant length of time without central heating, perhaps using secondary heating only (e.g. plug in electric heaters) or finding ways to get the boiler to work intermittently.

There is a lack of observed data on precisely how long low income households will go without a functioning heating system. However, we can derive estimates of both how many systems come to the end of their natural life each year and compare this to estimates of how many are estimated to be replaced on average each year. This allows us to estimate the number of heating systems each year that, in the absence of policy, break down and are not replaced. This calculation also allows us to estimate how many boiler replacements would have happened in the absence of policy, in order to estimate the net capital cost of intervening now rather than later.

Table 34: Illustration of method for estimating broken boilers and natural boiler replacement

	Year 1	Year 2	Year 3	Year 4
Number of fuel poor households in bottom nest with non-condensing boilers in 2015	535,000	535,000	535,000	535,000
Estimated broken boilers (cumulative)	44,583 *(1/12 x 0.535m)*	89,167 *(2/12 x 0.535m)*	133,750 *(3/12 x 0.535m)*	178,333 *(4/12 x 0.535m)*
Estimated number of natural boiler replacements (cumulative)	32,100 *(6% x 0.535m)*	64,200 *(12% x 0.535m)*	96,300 *(18% x 0.535m)*	128,400 *(24% x 0.535m)*
Net build-up of broken boilers	12,483	24,967	37,450	49,933

Table 34 illustrates the method used for estimating the build-up of broken heating systems in fuel poor households, and the rate of natural boiler replacement among these households in the absence of policy over four illustrative years. To estimate the number of broken boilers in each year we follow the approach adopted for the Affordable Warmth Target in the Green Deal and ECO Final Impact Assessment[44] in applying a probability-based 'broken boiler frequency'. This involves taking the average expected lifetime of a boiler – we assume 12 years for consistency with Green Deal and ECO Final IA – and assuming that every year 1/12 of the fuel poor group's boilers come to the end of their lifetime.

We then estimate the number of non-condensing boilers (broken or otherwise) that are naturally replaced using historical data from the EHS. This shows that over the last five years an average of 6% of households with non-condensing boilers each year have upgraded to condensing boilers. We therefore apply this average 6% to our target fuel poor group each year to estimate how many non-condensing boilers would naturally be replaced in the absence of policy. We also assume, conservatively, that all new condensing boilers in the counterfactual replace broken ones. We therefore estimate the net build-up of broken boilers as:

[Number of broken boilers] – [Number of natural boiler replacements] = Net Broken Boilers

We estimate the *net* capital and hidden costs by applying the same cost data to the intervention of installing condensing boilers as the counterfactual and taking the discounted difference. The estimated costs used are summarised in Table 35. The

[44] See Annex D, available at: https://www.gov.uk/government/consultations/the-green-deal-and-energy-company-obligation

capital cost estimates are informed by observed data from past Government energy efficiency schemes, while the hidden costs are taken from those used in the Green Deal and ECO Final Impact Assessment.

Table 35: Estimated capital costs, hidden costs and energy savings from installing condensing boilers

Measure	2015	2022	2027
Gas Condensing Boiler			
- Capital Cost	£2,050	£2,050	£2,050
- Hidden Cost	£97	£97	£97
- Average kWh annual saving*	2,600	2,600	2,600
Oil Condensing Boiler			
- Capital Cost	£3,100	£3,100	£3,100
- Hidden Cost	£97	£97	£97
- Average kWh annual saving*	2,990	2,990	2,990

** kWh savings vary by dwelling type and size and income group. This table shows an example of an average sized semi-detached home with an average income.*

To estimate the change in energy use from installing condensing boilers we apply estimated average actual kWh savings from observed data in NEED for gas heated homes. NEED does not hold data on non-metered fuels, therefore we estimate the equivalent savings for oil heated homes using a ratio of oil:gas consumption. This is estimated from a combination of data sources, including the Living Cost and Food Survey. The figure is an average of 1.15:1 on average. These savings are also summarised in Table 35.

Installing Central Heating

Technical potential for installing central heating in homes where there is none currently present is estimated from a projection of remaining opportunities after policies have delivered to 2015. This is summarised in Table 36, where all three ‘nests’ have been merged for reasons of sample size.

Table 36: Estimated technical potential to install new central heating in fuel poor households in England

Measure	2015	2022	2027
New Central Heating	145,000	144,000	140,000
- All nests	145,000	144,000	140,000

Source: EHS (2010), after impact of projected policy delivery to 2015

We assume for the counterfactual that households currently without central heating continue without central heating in the absence of policy intervention. While we expect in reality a small number of fuel poor households may upgrade to central heating without intervention, the significant upfront cost may deem this unlikely for the majority and the relatively small number of households without central heating means that the absolute rate of upgrade without intervention is likely to be negligible. We estimate the capital and hidden costs of installing central heating by applying the cost estimates summarised in Table 37. The capital costs are informed by observed cost data from previous Government energy efficiency schemes. The hidden costs are taken from the Green Deal and ECO Final Impact Assessment.

Table 37: Estimated capital and hidden costs of installing new central heating

Measure	2015	2022	2027
Gas Central Heating			
- Capital Cost	£2,200	£2,200	£2,200
- Hidden Cost	£835	£835	£835
Electric Central Heating			
- Capital Cost	£1,100	£1,100	£1,100
- Hidden Cost	£835	£835	£835
Oil Central Heating			
- Capital Cost	£3,200	£3,200	£3,200
- Hidden Cost	£835	£835	£835

In order to estimate the change in energy use from central heating installation, we first estimate the amount and type of energy used pre-intervention. For gas central heating, we assume – based on observations under the Warm Front scheme – that 40% of households with a gas connection present primarily use gas secondary heating (e.g. gas fires) and 60% use electric secondary heating (e.g. plug-in electric heaters). For electric and oil central heating interventions we assume electric secondary heating is used.

We estimate the kWh usage for secondary electric heating using SAP-based estimates, adjusting these down to reflect that we do not expect households using secondary electric heating to reach the SAP target temperatures, such as 21°C in the main living area. The Warm Front Evaluation[45] found that before heating upgrades were installed, low income households heated their main living space to around 18°C on average. We therefore adjust the SAP-based estimate of electric secondary energy consumption down by 3°C. For secondary gas heating we assume that households use the equivalent of 2°C less than typical gas

[45] Green and Gilbertson (2008). *Warm Front, Better Health*, available at: www.apho.org.uk/resource/view.aspx?RID=53281

consumption for their house type, based on the observation from the Warm Front Evaluation that pre-installation households heated to around 18°C and afterwards to around 20°C.

To estimate energy consumption post-intervention, we source typical gas consumption by dwelling type, size and income group from NEED. To estimate the equivalent energy usage for oil and electric central heating we again apply ratios of electricity:gas and oil:gas from other data sources, such as the Living Cost and Food Survey. The pre- and post-intervention energy use assumptions a representative semi-detached house are summarised in Table 38.

Table 38: Estimated energy use before and after installing new central heating for typical semi-detached dwelling

Measure	Pre-Intervention (kWh)		Post-Intervention (kWh)	
	Gas/Oil	Electricity	Gas/Oil	Electricity
Gas Central Heating	12,654 *(for 40% of households)*	10,128 *(for 60% of households)*	15,622	0
Electric Central Heating	0	10,128	0	12,745
Oil Central Heating	0	10,128	17,966	0

Source: DECC estimates based on NEED and SAP 2009

Installing Renewable Space Heating Technologies

Technical potential to install renewable space heating technologies is currently estimated in the FP-MACCs based on an assumption that any dwelling can potentially receive an air-source heat pump but that only rural properties that are not flats are suitable for a ground-source heat pump or a biomass boiler. The estimated technical potential for renewable heat is set out in Table 39. We will continue to develop our methodology in order to build a more sophisticated approach for the next update of FP-MACCs in the final fuel poverty strategy.

Table 39: Estimated technical potential to install renewable heat in fuel poor households in England

Measure	2015	2022	2027
Air-source heat pumps	2,413,000	2,467,000	2,456,000
Ground-source heat pumps	492,000	495,000	509,000
Biomass boilers	308,000	312,000	312,000

Source: EHS (2010), after impact of projected policy delivery to 2015

As with condensing boilers, it is important to take into account the natural replacement of heating systems in the absence of policy when estimating the net capital and hidden costs of renewable heat technologies. We therefore apply the same counterfactual for renewable space heating measures as described for condensing boilers above. The capital costs applied to the number of renewable heat interventions adapted from the September 2012 Renewable Heat Incentive Impact Assessment.[46] These estimates include an estimated 20% reduction in capital costs between 2013 and 2020. The hidden costs used in the RHI analysis are included as part of wider barrier costs to taking up renewable heat measures, and are not necessarily consistent with those used for other heating measures in the FP-MACC. We therefore apply the same hidden costs to renewable space heating technologies as for installing new central heating. Some example costs for an oil-heated detached dwelling are summarised in Table 40.

Table 40: Illustrative costs of installing renewable heat in an average oil-heated detached property

Measure	2015	2022	2027
Air Source Heat Pump (ATW)			
- Capital Cost	£14,983	£12,712	£12,712
- Hidden Cost	£835	£835	£835
Ground Source Heat Pump			
- Capital Cost	£21,361	£18,124	£18,124
- Hidden Cost	£835	£835	£835
Biomass Boiler			
- Capital Cost	£10,344	£8,777	£8,777
- Hidden Cost	£835	£835	£835

To estimate the change in energy use, we use the typical consumption of gas, electricity and oil derived from NEED described above, and apply renewable heat efficiency factors used in the Renewable Heat Incentive September 2012 Impact Assessment. It is important to note that the performance of renewable heating technologies assumed here is based on the design data DECC collected through Renewable Heat Premium Payment scheme, which has been analysed by DECC. It is not based on actual performance data as would be collected in a field trial or monitoring programme. As such as **there is significant uncertainty around the performance of renewable heating technologies** and the interpretation of results should be treated with a high degree of caution. We will continue to update the FP-MACC with emerging evidence on renewable heat technologies.

[46] Available at: https://www.gov.uk/government/policies/increasing-the-use-of-low-carbon-technologies/supporting-pages/renewable-heat-incentive-rhi

The renewable heat efficiency factors are used to estimate the total kWh of fuel needed to run a renewable heat technology compared to the total kWh needed to run the original heating system. An example of the factors used and how original fuel use is transformed into an estimate of renewable heat fuel use is summarised in Table 41.

Table 41: Illustration of conversion from gas fuel use to renewable heat fuel use*

Measure	Gas kWh pre-intervention	Efficiency Factor	Electricity (Heat Pumps) / Biomass kWh
Air Source Heat Pump	15,622	0.31	4,804
Ground Source Heat Pump	15,622	0.26	4,062
Biomass Boiler	15,622	1.09	17,028

***** There is significant uncertainty around the true performance of renewable heat technologies. These conversion factors should be interpreted with caution.

Estimating the social costs and benefits of energy bill rebates

Energy bill rebates can be received by any fuel poor household irrespective of their dwelling type or heating fuel. Therefore technical potential for rebates is based on the number of households in each ‘nest’ in the year in consideration.

Energy bill rebates do not entail any capital costs. When assessing rebates independently of policy costs, as we do for the purposes of a technical FP-MACC, they are simply a transfer from one group (e.g. all taxpayers, or all bill payers) to another (those in receipt of a rebate). This means the equivalent to capital costs, as described in this section for other interventions, are zero for bill rebates.

Changes in energy use that result from receiving a rebate are dependent on a number of factors, with the main one being the size and duration of the rebate. We assume for the FP-MACC that all rebates are worth £130 in 2012 constant prices and last for a single year. There is limited evidence at present as to how much additional energy expenditure arises from rebates of this size, therefore we use evidence from the Institute for Fiscal Studies – based on evidence relating to the Winter Fuel Payment – to assume that 41% of the value of energy bill rebate will be spent on extra heating fuel. As the value of the rebate is fixed in real terms, this means that the change in energy is dependent on prices in the year in question. Examples of how changes in energy use are calculated based on the prices at different points in time are detailed in Table 42.

Table 42: Estimated increases in energy use as a result of energy bill rebates for fuel poor households in England

Heating Fuel Type	2015	2022	2027
Value of rebate	£130	£130	£130
Gas			
Central retail price of gas (£/kWh)	0.054	0.053	0.051
Increase in energy use (kWh)	987	1,006	1,045
Electricity			
Central retail price of electricity (£/kWh)	0.182	0.205	0.204
Increase in energy use (kWh)	293	260	261
Oil			
Central retail price of oil (£/kWh)	0.064	0.067	0.070
Increase in energy use (kWh)	833	796	761

Increases in energy use are valued using the Long Run Variable Cost of energy supply, and the resulting emissions and air quality changes are valued using the same approach as for insulation and heating interventions. These increases in energy use are also purely the result of comfort taking, which is valued at the retail price of the main heating fuel of the household receiving the rebate.

Measure Lifetimes

The net social cost calculations for all interventions are for their estimated lifetimes. These are summarised in Table 43.

Table 43: Estimated lifetimes of FP-MACC interventions

Measure	Years
Cavity Wall Insulation	42
Loft Insulation	42
Solid Wall Insulation	36
Condensing Boiler	12
New Central Heating	12
Air Source Heat Pump	20
Ground Source Heat Pump	20
Biomass Boiler	20
Energy Bill Rebate	1

Source: Insulation, Condensing Boilers and New Central Heating – Green Deal and ECO Final Impact Assessment; ASHP, GSHP and Biomass Boiler –September RHI Impact Assessment; Energy Bill Rebate – assumed.

FP-MACC Results

The FP-MACC for 2015, 2022 and 2027 are shown in Figure 9, Figure 10 and Figure 11 respectively. The colours of the bars denote the type of fuel poor households that are receiving measures: blue bars show opportunities to supports households in the bottom nest, green shows the middle nest and purple denotes the top nest (i.e. least severe fuel poverty).

Each of the curves shows that there is significant cost-effective potential to support fuel poor households and many of the options relate to severely fuel poor households. As we would expect, low-cost insulation and heating measures make up some of the most cost-effective measures. The curves also suggest that there is some potential for cost-effective delivery of more expensive insulation measures and renewable heat in severely fuel poor households, although given the high degree of uncertainty around the in situ performance of renewable heat technologies it is necessary to treat this finding with caution.

The picture changes over time. Rising energy prices and the assumed fall in the cost of some of the more costly technologies changes the relative attractiveness of measures. Specifically some of the potential for renewable heating and solid wall insulation starts to look more cost-effective (i.e. shifts leftwards on the curves).

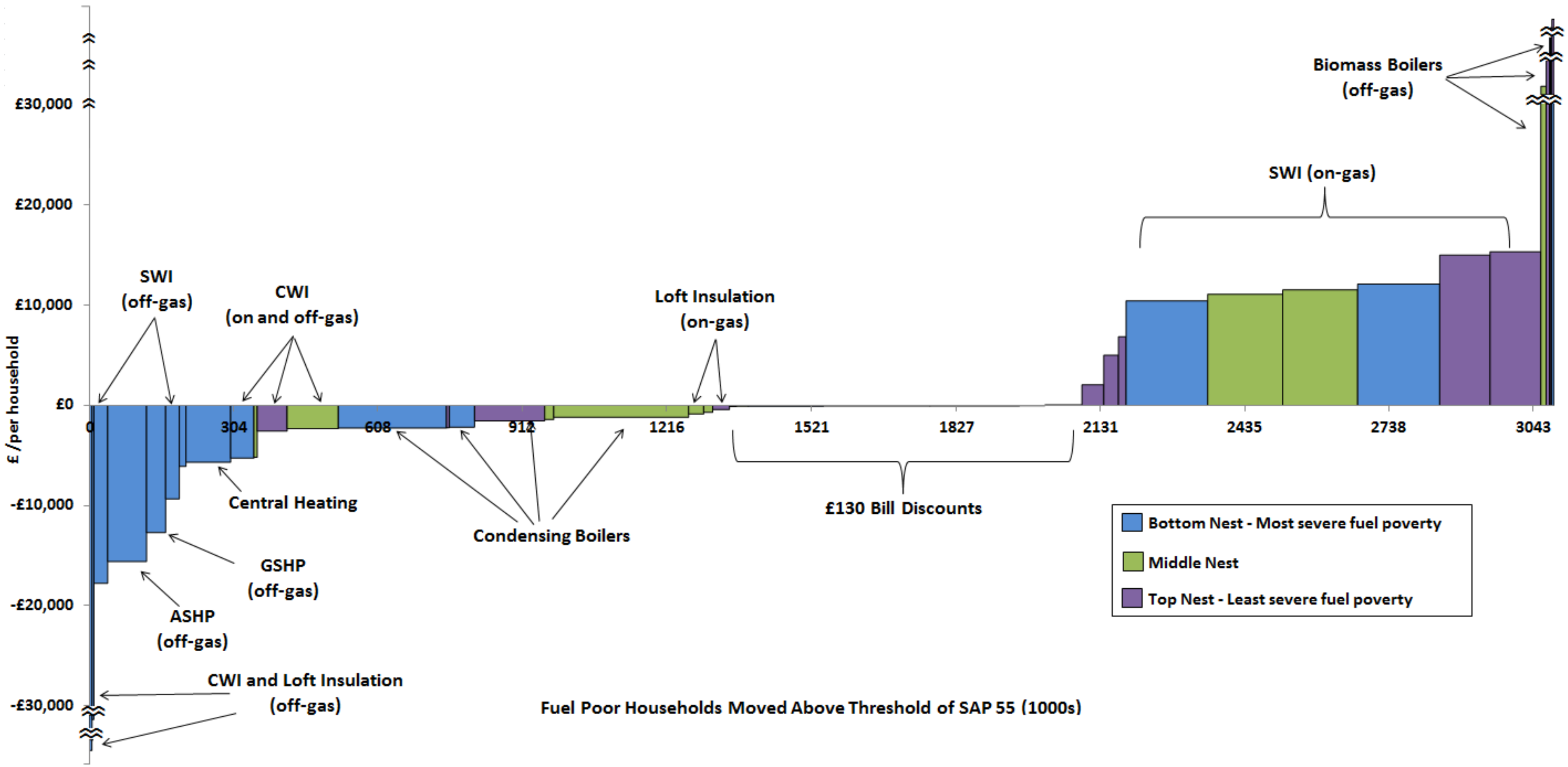

Figure 9: fuel poverty marginal alleviation cost curve in 2015

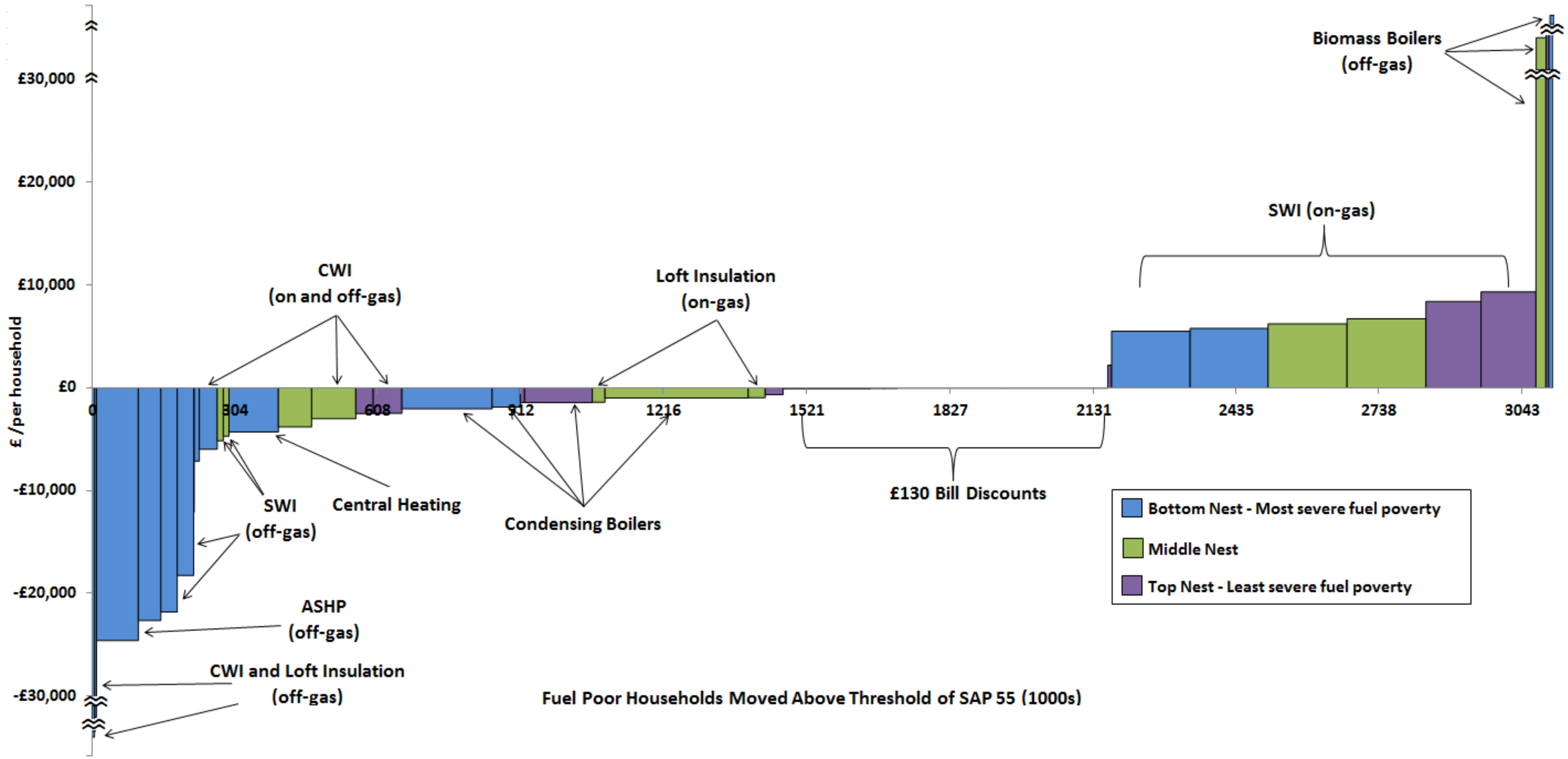

Figure 10: fuel poverty marginal alleviation cost curve in 2022

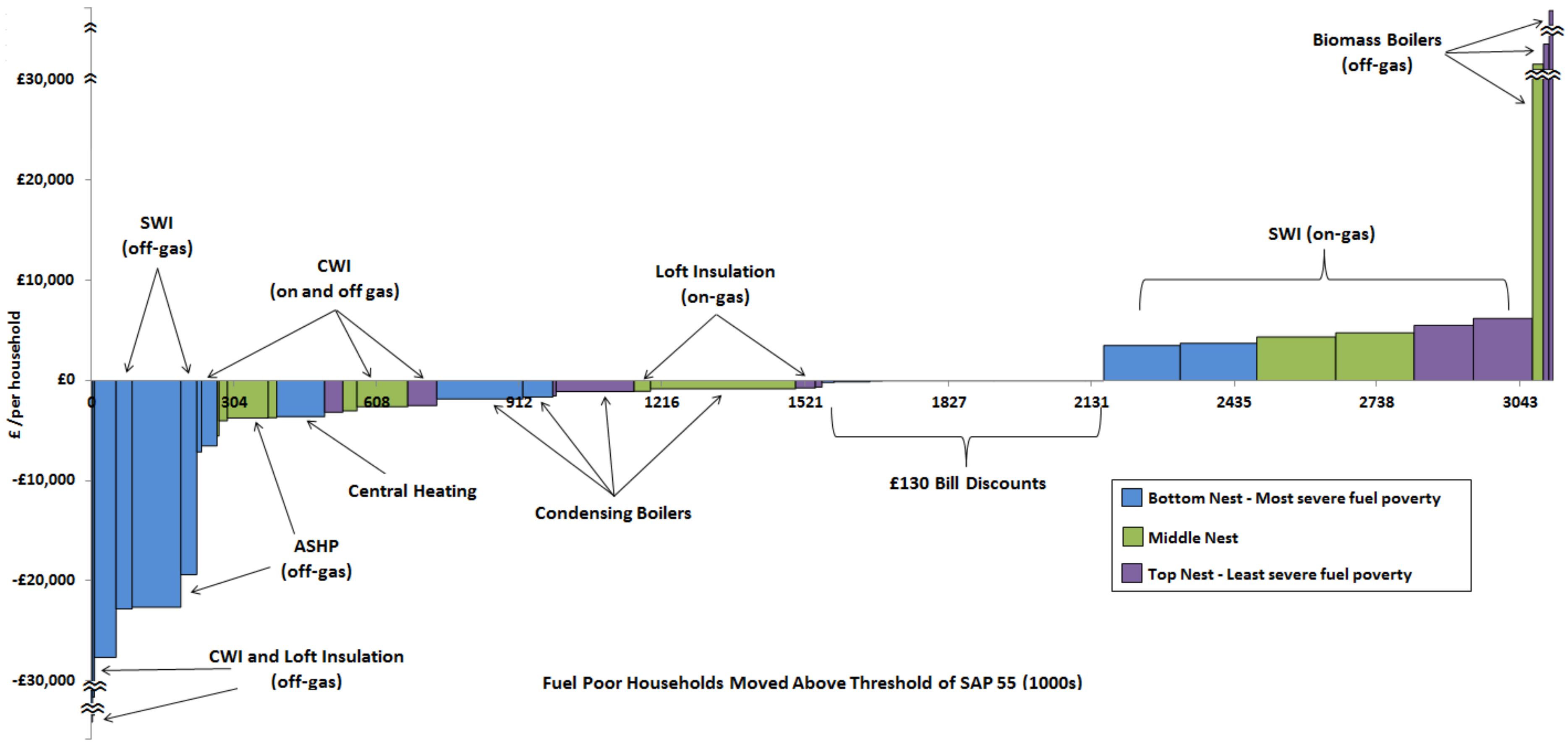

Figure 11: fuel poverty marginal alleviation cost curve in 2027

Uncertainty and sensitivity testing

The FP-MACC analysis is based on a large number of assumptions – not only projections about the future path of incomes and energy prices but also assumptions about the potential and costs of different efficiency measures. Naturally, each of these is uncertain. This means that we always have to exercise caution in interpreting the outputs. The degree of uncertainty also means that it is important that we undertake sensitivity testing to understand whether the results are robust to changing input assumptions.

Figure 12 and Figure 13 show the FP-MACC for 2027 in the high and low scenarios. In these scenarios we change the assumptions on energy prices and incomes (based on the range of assumptions set out in Section 4). As we would expect, many energy saving measures look more cost effective in the high scenario. This means that more measures look cost-effective (i.e. deliver net social benefits) but there are also some changes to the merit order. In particular, energy bill rebates (whose value is unrelated to the level of energy prices) look less attractive in pure cost-effectiveness terms compared to the central scenario. The opposite is true in the low scenario.

As set out above, we will continue to develop the FP-MACC over the coming months. Part of this process will include testing the conclusions against alternative policy assumptions – particularly around the costs associated with different measures.

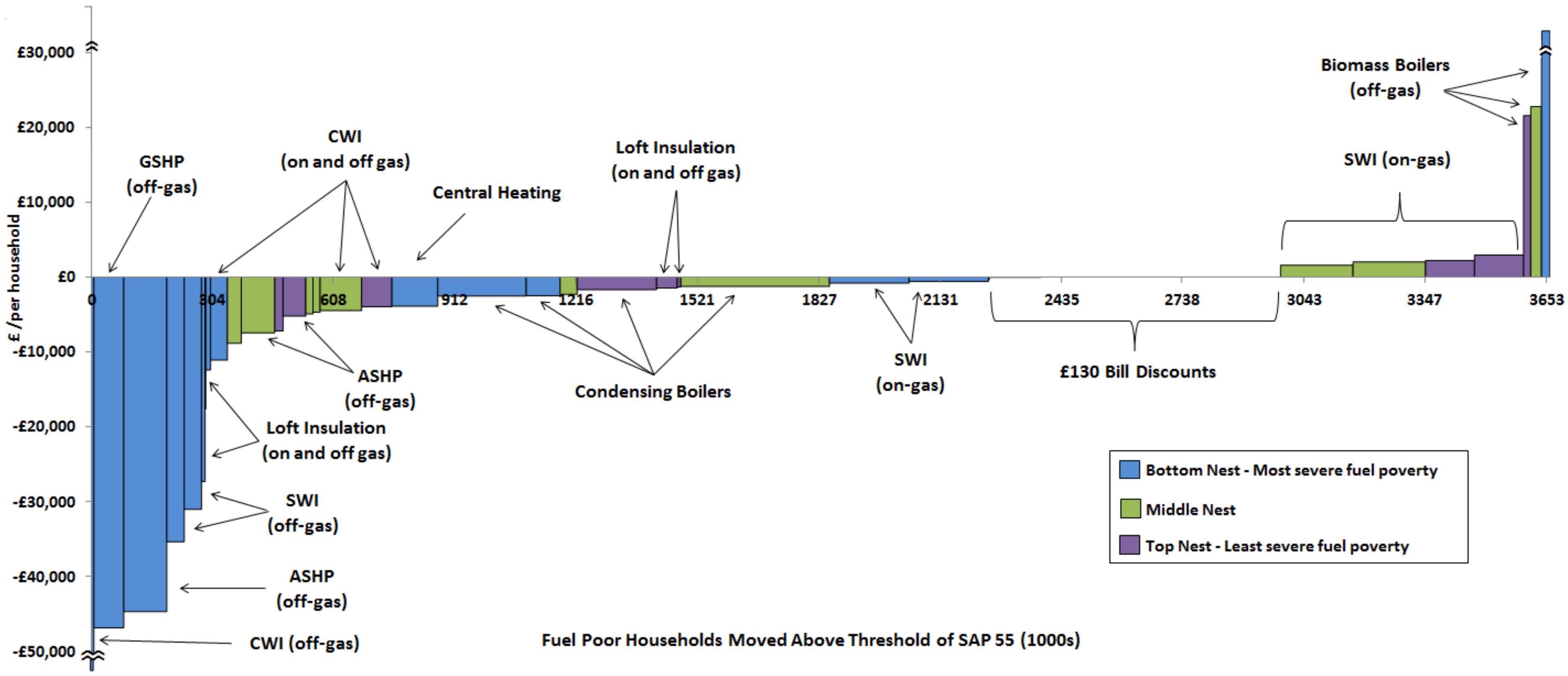

Figure 12: fuel poverty marginal alleviation cost curve in 2027 – high scenario

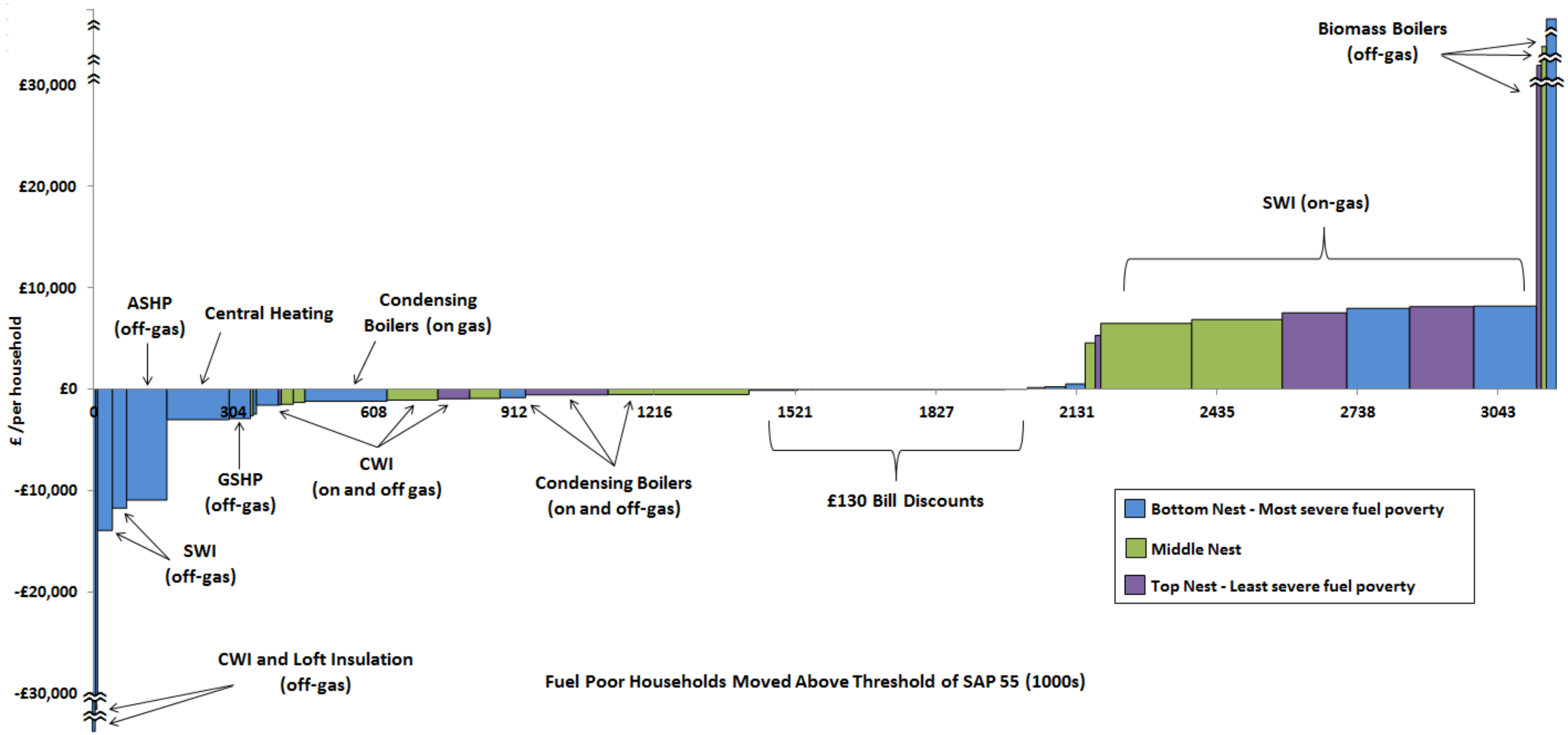

Figure 13: fuel poverty marginal alleviation cost curve in 2027 – low scenario

Section Six: Measuring the health impacts of cold homes

Introduction

The Hills Review stated one of the reasons that fuel poverty is a distinct problem is because living at low temperatures due to fuel poverty can be a contributor to a number of incidents of ill health, including Excess Winter Deaths.

This annex explains how the LIHC framework – as a means of defining and measuring fuel poverty – responds to the vulnerability of certain types of people in estimating household energy requirements and discusses the limits of this approach in capturing vulnerability to negative health outcomes. We stated in Section One that we are working to be able to better measure and monetise the health impacts associated with fuel poverty. Doing so would mean that estimates of the NPV of fuel poverty policies could capture health impacts. The following sections present work to date to build a model that estimates the monetary value of the health impacts from energy efficiency measures called the 'Health Impacts of Domestic Energy Efficiency Measures' (HIDEEM) model, some of the results from this model and some next steps for taking forward this work.

The LIHC framework does not explicitly account for the vulnerability of people's health to living in low temperatures and fuel poverty. However it does partially reflect vulnerability through the methodology used to measure household energy requirement. This is measured by multiplying:

a. Time spent heating the home, by
b. The KWh required to heat the home to 21 degrees in the main living area and 18 degrees in the remainder of the house, by
c. The average tariff (p/KWh)

Currently (a) is tailored to an individual's circumstance. A standard heating regime assumes that the occupants are not in the dwelling during normal working hours. In this case it is assumed that the occupant heats the dwelling for two hours in the morning and then for seven hours from late afternoon. During the weekend it is assumed that the property is heated throughout the day for 16 hours. However, this heating pattern does not apply for large sectors of the population (in particular, 'vulnerable' households, such as elderly and those caring for young children).

From 2001, the EHS interview survey included a direct question to ask whether anybody within the household occupied the dwelling during the morning or afternoon. This question is directly utilised to approximate the heating pattern. If anybody is in the house in *either* the morning or afternoon during weekdays, the house is assumed to require all day heating. In these cases all day heating is assumed throughout the week when measuring a household's heating requirements. Therefore, the current methodology to calculate the time spent heating the home does account for personal circumstances meaning that vulnerable households tend to have higher modelled energy requirements (and, all things being equal, are more likely to be fuel poor).

The interim report of the Hills review, *Fuel Poverty: The Problem and its Measurement*, set out the current evidence on the types of households that are more likely to be vulnerable to the negative health effects from living in fuel poverty. It identified the following people:

- Those over 75 years old
- Those under 5 years old
- Those with a long term illness or disability

Around 47% of households contain someone in this 'vulnerable' group (EHS 2010). Further statistics on this group of people in relation to the LIHC framework is shown below in Table 44. As we would expect – based on the assumed heating regime – vulnerable households are over-represented amongst the group of fuel poor households.

Table 44: LIHC and vulnerable households

Household Type	No. of households in LIHC (000)	Proportion of households in LIHC (%)	Average Fuel Poverty Gap (£)
Not vulnerable	2,474	11.6%	£405
Vulnerable	1,332	13.2%	£408

Monetising Health Impacts

Typically, the government uses cost-benefit analysis to assess the economic impact of fuel poverty policies – where the overall impact is expressed in terms of a net present value (NPV). However, these NPV values do not currently measure health impacts. This is because we do not yet have a robust methodology for measuring the improved health outcomes that can result from policies.

We have been working with a team of leading experts from University College London and London School of Hygiene and Tropical Medicine to develop a model to estimate the change in occupants' health from the installation of energy efficiency measures (resulting from changes in the indoor temperature and pollutant exposure). The model that was developed is the HIDEEM model.

HIDEEM uses the EHS as a basis for the analysis. The model is built from a number of inter-related modules covering a building's permeability properties and individual health conditions. Pollutants included in the model that impact on health are: particulate matter, tobacco smoke, radon gas and mould growth. The health conditions linked to these pollutants include heart and circulatory diseases, cancers and strokes, as well as respiratory illness and common mental disorders. HIDEEM uses the Quality Adjusted Life Year (QALY) method to monetise these health impacts. This involves placing a value on a year of perfect health and assessing changes from this state. Figure 14 below represents a simple schematic of the HIDEEM model.

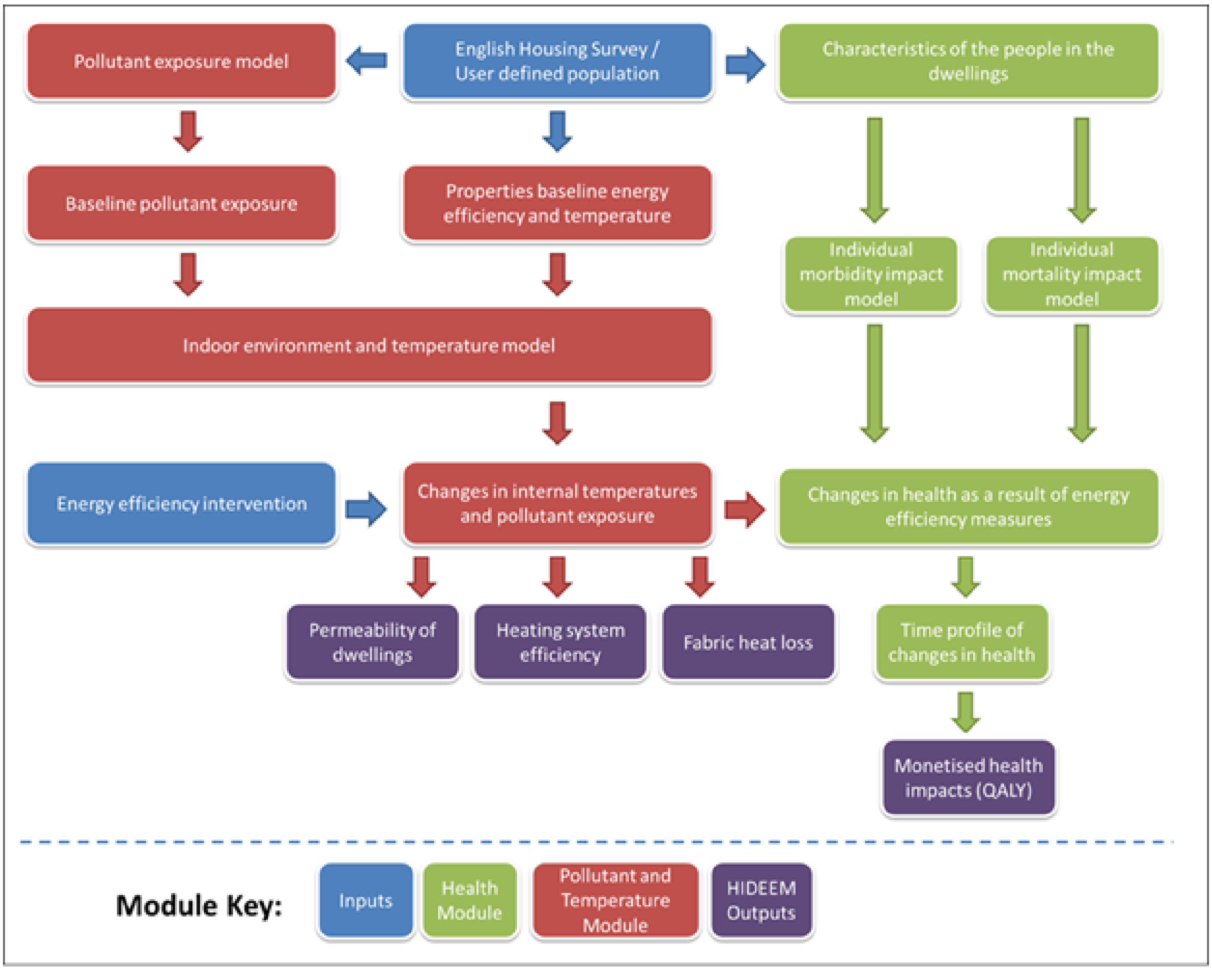

Figure 14: Overview of HIDEEM model

Results: the value of health improvements

The results from the HIDEEM model – which show the Present Value (PV) of the health benefits associated with different insulation and heating measures – suggest that insulation measures produce a larger health benefit compared to heating measures, as shown in Figure 15. This is driven by the fact that insulation measures last around three times as long as heating measures, therefore allowing for a longer time frame for benefits to accrue.

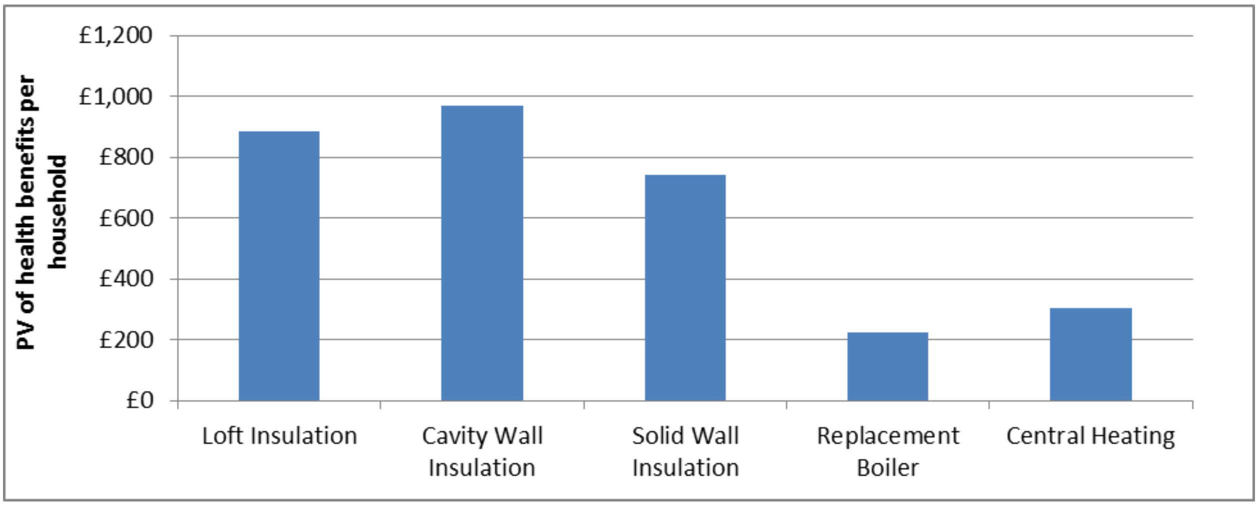

Figure 15: PV of Energy Efficiency Measures

The results of some sensitivity tests around these values are shown in Table 45 – where the range is driven by changing the assumption around the length of time for which health effects are sustained. The low scenario depicts benefits lasting for the duration of the measure only. The central scenario shows benefits lasting for a further 5 years beyond the duration of the measure. This is based on the idea that it typically takes a number of years for the full health benefits of an insulation or heating measure to be realized by the occupant. The model therefore assumes that it takes a similar amount of time for these health benefits to recede on a linear path. The high scenario assumes that benefits are sustained for a longer period beyond the duration of the insulation or heating measure – health benefits are assumed to last for 1.5 times the measure lifetime. As discussed below, we recognize the limitations of these assumptions and will work in the near term to improve upon them given the best available evidence.

Table 45: Sensitivity Results of Health Analysis

Measure		Low	Medium	High
Loft Insulation	Duration of benefits	42 years	47 years	50 years
	PV / measure	£703	£885	£1,025
	QALY / measure	0.034	0.045	0.053
Cavity Wall Insulation	Duration of benefits	42 years	47 years	50 years
	PV / measure	£758	£969	£1,139
	QALY / measure	0.037	0.049	0.060
Sold Wall Insulation	Duration of benefits	36 years	41 years	50 years
	PV / measure	£592	£742	£1,195
	QALY / measure	0.027	0.036	0.063
Replacement Boiler	Duration of benefits	12 years	17 years	18 years
	PV / measure	£127	£224	£246
	QALY / measure	0.005	0.009	0.010
Central Heating	Duration of benefits	12 years	17 years	18 years
	PV / measure	£172	£303	£332
	QALY / measure	0.006	0.012	0.013

Next Steps

Our intention is that we will ultimately be able to incorporate these results into economic appraisals and into the FP-MACC analysis (see Section Five). This will help us to fully capture the benefits associated with fuel poverty policies. However, more work needs to be done to be able to integrate these benefits into economic appraisal – in particular, we will need to incorporate the impacts in a way that accounts for comfort taking (which at least partially reflects health benefits) to ensure that we are not double counting benefits.

In addition, we will continue to work to build the evidence base around the key assumptions required for this analysis which will remain under scrutiny for their robustness as this analysis progresses. These are: (a) the duration health benefits from a measure last for; and (b) the ventilation measures installed with the energy efficiency measure.

Section Seven: Measuring energy efficiency

Background

In the accompanying publication, *Fuel Poverty: A Framework for Future* Action, we have proposed a new form for the fuel poverty target for England, based on improving the energy efficiency of households in fuel poverty. Setting a future target on the basis of the energy efficiency of fuel poor homes requires a choice to be made in relation to how energy efficiency is to be measured. A number of alternative approaches already exist in the UK, the most prominent of which are:

- The Standard Assessment Procedure (SAP) indicators:
  - The energy cost rating (SAP score);
  - The Environmental Impact (EI) rating;
  - The Dwelling CO_2 Emission Rate (DER); and
- The National Home Energy Rating.

SAP Indicators

SAP is the Government's official methodology for assessing the energy performance of dwellings.[47] It is used to determine the A to G bands on Energy Performance Certificates. The SAP methodology details an approach to calculating how much energy is required to meet a standardised heating regime (e.g. heating the home for two hours in the morning and four hours in the evening) to meet prescribed indoor temperatures (e.g. 21°C in the main living area) in the dwelling being assessed, in addition to standardised assumptions about the amount of lighting required. A range of factors are included in the calculation, including the consideration of:

- The building materials used to construct the dwelling;
- The extent to which the building fabric has been insulated (e.g. whether the dwelling has loft and/or wall insulation);
- How well ventilated the building is;
- The efficiency of and degree of control over the dwelling's heating system;
- The type of fuel(s) used to heat, cool, light and (where applicable) ventilate the home; and
- The presence of any renewable energy technologies.

The methodology therefore produces a dwelling-specific estimate of the amount of energy required for heating, cooling and lighting for a year. Cooking and appliances are excluded and for most purposes the geographical location of the dwelling within the UK is not taken into account. This estimate of required energy can then be translated into the three SAP indicators: (1) the SAP score; (2) the environmental impact rating; and (3) the dwelling CO_2 emission rate.

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[47] For a more detailed explanation of the SAP methodology, see: http://www.bre.co.uk/SAP2009

Indicator 1 – the SAP rating

The SAP rating provides a measure of a dwelling's energy efficiency based on the costs of the estimated annual energy requirement for heating, cooling, ventilation and lighting, less the energy saved from the presence of renewable energy technologies, such as solar panels. The dwelling's estimated costs are then adjusted for floor area, enabling straight forward comparisons of efficiency across different sizes of dwelling. This is then expressed on a scale from 1 to 100, with 1 representing very inefficient dwellings (essentially homes with high energy costs) and 100 representing very efficient dwellings (low running costs).

The SAP rating's use of estimated energy *costs* rather than just simply units of energy means that it not only captures differences between dwellings based the thermal efficiency of the building fabric, but also captures the effect of relative differences in prices across alternative heating fuels. This means, for example, that two dwellings identical in all respects other than their use of main heating fuel have different SAP ratings (a gas-heated home would have a higher SAP rating than an electrically-heated home, because electricity is typically the more expensive fuel).

Indicator 2 – the Environmental Impact (EI) rating

The EI rating is calculated in a near identical fashion to the SAP rating. The key difference is that instead of focusing on the estimated *costs* associated with a dwelling's energy use, the EI rating focuses solely on the net CO_2 emissions that would arise. Like the SAP rating it is expressed on a scale of 1 to 100, with 1 representing a high environmental impact (high carbon emissions) and 100 a low impact (low/zero emissions).

The EI rating's focus on carbon emissions means that it captures aspects of the thermal efficiency of a dwelling while also reflecting the carbon intensity of the main heating fuel used. For example, for the same two identical dwellings referred to above – one electrically-heated and the other gas-heated – the latter would be assigned a higher EI rating on the basis that at present gas is less carbon-intensive than electricity (i.e. burning gas emits less carbon per unit of energy used).

Indicator 3 – the Dwelling CO_2 Emission Rate (DER)

The DER is a similar indicator to the EI rating and is primarily used for compliance with building regulations. It is calculated in the same way as the EI rating, but is expressed as units of CO_2 emitted per m^2 of floor area per year, instead of being expressed on a 0 to 100 scale.

The National Home Energy Rating (NHER)

The NHER is an energy assessment accreditation scheme and energy efficiency rating system. It sets out an alternative approach to estimating the energy use of a dwelling. Like SAP, the NHER uses a set of standardised assumptions about occupancy and heating regimes to ensure comparability, however it utilises a different set of criteria. Some key differences from the SAP methodology are:

- The inclusion of estimated energy use from cooking and appliances (e.g. washing machines);

- The inclusion of factors that adjust estimated energy use on the basis of local climate conditions, therefore allowing identical dwellings in different parts of the UK to achieve different ratings.

The NHER focuses on the *costs* of estimated energy requirements, and is expressed on a scale from 0 to 10 with 0 representing poor efficiency and 10 representing high standards of efficiency. Similarly to the SAP rating, this means that identical dwellings using different main heating fuels would be assigned different NHER scores, with lower cost heating fuels achieving a higher rating. Alternatively, two dwellings identical in all ways except their location and climatic conditions or number of appliances could potentially be assigned different ratings.

Suitability for setting a fuel poverty target

Of the energy efficiency measures summarised in this section, the two most appropriate indicators in relation to fuel poverty are the SAP rating and the NHER. This is primarily because of their focus on the standardised *costs* of energy – naturally a key concern and driver for Low Income High Cost households – rather than being primarily concerned with carbon emissions, as in the case of the EI rating and DER.

The SAP rating and NHER share a number of common strengths:

- Both approaches have the ability to incorporate a detailed level of information about a dwelling and its characteristics when estimating energy costs;
- They use standardised heating and occupancy regimes to facilitate simple comparisons across dwellings; and
- They allow differentiation between households on the basis of relative fuel prices.

However, from the viewpoint of selecting an efficiency measure against which to set a potential future target, we are minded to adopt a methodology based on the SAP rating. This is primarily because SAP is a widely used and recognised benchmark for energy efficiency, and adopting a SAP-based target metric would align front line delivery of energy efficiency with fuel poverty objectives. SAP ratings are already used to rate homes for Energy Performance Certificates and bespoke SAP assessments are pivotal to the delivery and reporting of key relevant Government policies such as the Green Deal and Energy Company Obligation. Adopting an energy efficiency measure for a fuel poverty target that aligns with current front line policy delivery would directly link fuel poverty objectives to wider energy efficiency goals. However, we will continue to work – including with interested stakeholders - to refine our thinking on the most appropriate measure of energy efficiency and will bring forward a proposal in the fuel poverty strategy.

Potential adjustments to a SAP-based metric

A SAP-based metric for a fuel poverty target would provide strong incentives to improve the energy efficiency of fuel poor households. Its use of a 0 to 100 scale means progress would be transparent and set out in a form that is understandable and simple to monitor progress against. However, despite its emphasis on energy costs, one key factor that is currently not reflected in the SAP methodology is the inclusion of other types of fuel poverty support that impact directly on energy bills (e.g. rebates).

Policies that subsidise energy costs directly reduce energy costs for households regardless of the thermal efficiency of their dwelling. Further, upgrading the energy efficiency of fuel poor homes will take time, and direct energy bill support is particularly effective at reducing costs in the meantime.

Given the relevance of energy bill rebates in reducing energy costs, we propose creating an energy efficiency measure that replicates the SAP rating methodology, with an adjustment made to allow for direct energy bill support. This would be a bespoke energy efficiency measure created solely for the purposes of setting and monitoring progress against a fuel poverty target, and would not amend in any way the official SAP methodology. It would be important to note that ratings under this proposed metric would only vary from 'standard' SAP ratings in those instances where a household is in receipt of a recognised direct energy bill rebate.

Creating this proposed extension to SAP to allow for direct bill support is a relatively straight forward adjustment in technical terms. As outlined above, the SAP rating indicator is in essence a four stage process:

1) Calculate a dwelling's estimated energy costs for heating, cooling, ventilation and lighting;
2) Subtract from those costs the savings generated from any renewable energy technologies present (e.g. solar panels) to arrive at estimated *net* energy costs;
3) Adjust the estimated net energy costs by floor area for comparability across dwelling sizes; and
4) Place the dwelling into the 0 to 100 scale relative to the efficiency score of all other dwellings.

The proposed adjustment would be made as part of stage (2), whereby an energy bill rebate would be treated in the same way as the cost savings generated by any renewable energy technologies present.

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