# APPENDICES

The appendices for Towards a Low-Carbon Peabody report in more detail the assumptions and methods used, and some additional tables of results that were not included in the main report. The contents of the appendices are as follows:


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# 1 Appendix I: Description of the Peabody Energy Model

The Peabody Energy Model has been developed using Microsoft Excel to quantify energy use, carbon emissions, refurbishment-related costs and fuel costs for Peabody residents from the base year 2006 to 2030. The structure of the model, and its principal assumptions and outputs are illustrated in figure 1.1 below. The description in this section is intended to give a basic summary of the key methods and assumptions used to design and implement the model.

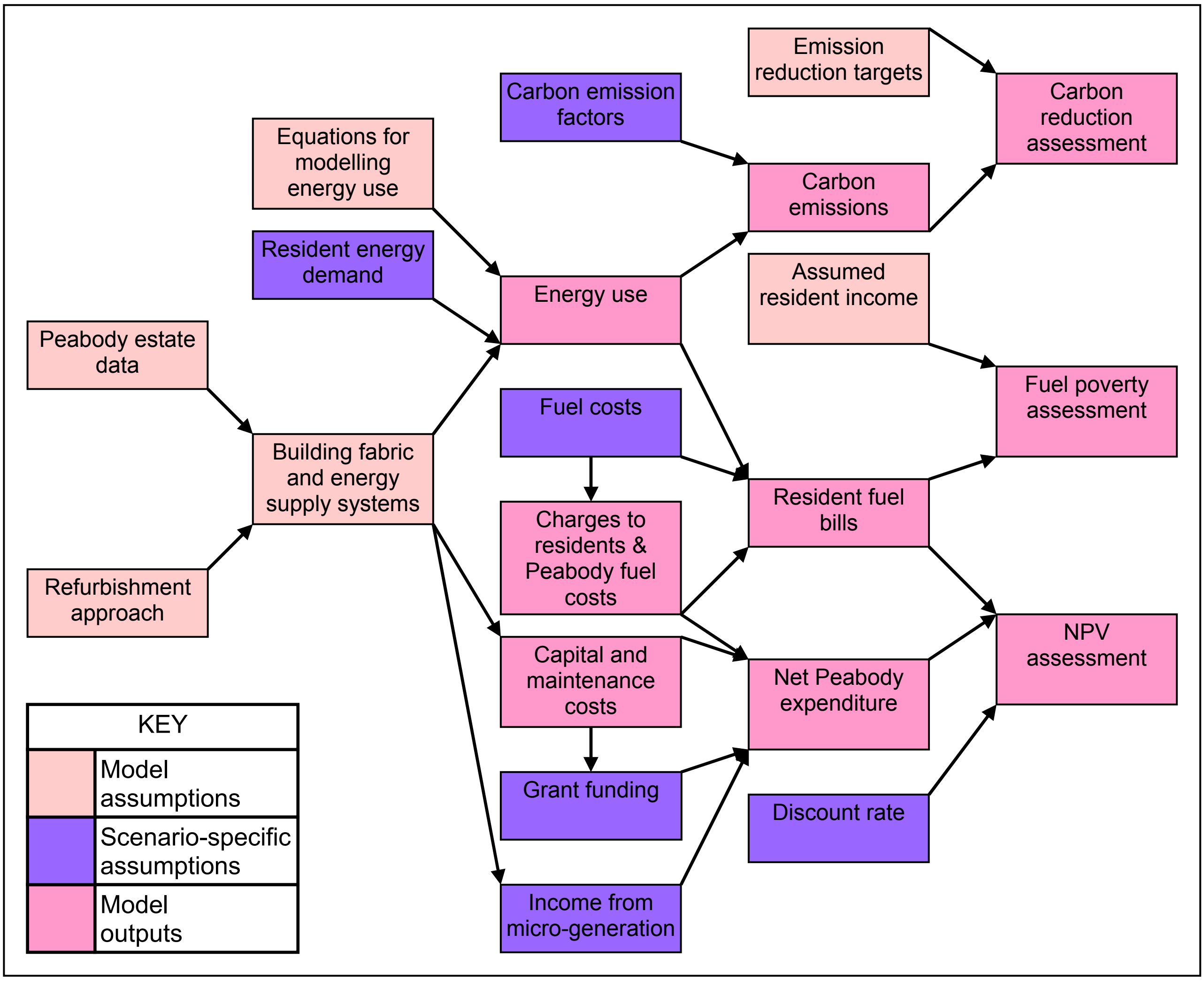


*Figure 1.1 The Peabody Energy Model*

## 1.1. Estates Modelled

In total, 189 Peabody estates were modelled, consisting of 16,901 dwellings in the base year 2006. Leaseholder dwellings on estates were excluded from the analysis, and six other existing estates were not modelled. Of the excluded estates, three of these were estates for which Peabody has no maintenance responsibilities (Percy Circus, Royle House and Swansea Court). The Clapham estate was not considered as it is currently being sold by Peabody. Two other estates were omitted as recommendations for refurbishment would have little practical value due to the high standards already in place. These were BedZED, which is already an exemplar low-energy estate, and the occupied parts of the Coopers Road development (which is only partially complete), which already have a low energy demand for space heating, and are due to be connected to a gas-fired combined heat and power (CHP) system when the development is complete.

Estates were grouped together according to their current and potential future energy servicing regimes (table 1.1).

| | |
|---|---|
| Individual gas boilers | 125 estates, comprising 6,487 units, where individual gas boilers are the dominant heating system |
| Part gas, part electric | 3 estates, comprising 126 units, heated by either gas boilers or electric storage heaters |
| All electric | 13 estates, comprising 332 units, where all energy is currently supplied by electricity |
| Communal | 16 estates, comprising 2,815 units, where some or all of the units are heated with communal systems. Typically, the existing communal systems supply heat to sheltered housing blocks |
| Communal potential | 32 estates, comprising 7,141 units, each having the potential for estate-wide communal heating to be installed |

*Table 1.1 Groupings of Peabody estates*

Estates were grouped in the Communal Potential group if they were built in blocks and had a minimum of 100 dwellings. This decision reflects experience that communal heating is more likely to be financially viable for higher density estates, where expenditure on heat distribution pipework is minimised, and for larger estates, as installation and maintenance costs per dwelling typically decrease as the number of dwellings increases. A review of energy efficiency at Peabody in 2007 estimated the minimum number of units required for CHP to be financially viable at 100–200 (Peabody Trust 2007).

Based upon these figures, the lower limit of 100 estates was used as a minimum number of units for estate-wide CHP to be considered in the Peabody Energy Model. Where an estate consists of blocks of flats and separate houses, only the dwellings in blocks were considered for installation of new communal systems. This assumption is not intended to imply that CHP systems serving less than 100 homes could never be a viable technical option on Peabody estates. This decision was made so that the impacts of installing CHP systems on larger, high-density Peabody estates, an intervention that has been recommended to Peabody, could be explored.

For all estates equipped with individual gas boilers, each estate's boiler installations were classified as either New (meaning that all homes are fitted with modern combination boilers) or Old (meaning that the estate contains a mixture of modern boilers, old boilers, room heaters and a small percentage of homes with electric storage heaters). This distinction reflects the two broad classes of servicing regimes found on Peabody estates where gas boilers are installed.

These classifications were used to determine the average boiler efficiencies on each estate, using data from Peabody on the proportions of each boiler type installed, and boiler efficiency data given in section 1.5 from the UK Government's Standard Assessment Procedure (SAP) for assessing energy efficiency of dwellings (BRE 2006). The assumed average boiler efficiencies were used alongside data from Peabody for the proportions of heating and hot water supplied by gas and electricity for estates with Old and New installations, to produce values for gas and electricity used on each estate for each year.

## 1.2. Estate Data

***Data obtained from Peabody***

Data on each estate were collected from Peabody staff and Peabody's internal documents and databases. Items used for the model that were taken from, or inferred from, these sources for each estate are: year of construction; number of units; built form (blocks/terraces/scattered houses); energy supply systems; average number of  residents per unit; average number of bedrooms per unit; year of Decent Homes work; listed/conservation area status; inclusion in disposals strategy; glazing type installed; number of houses/bungalows; fraction of houses/bungalows with gardens; fraction of dwellings with flat roofs; number of homes currently supplied by communal heating system; number of units with gas cookers; number of storeys; roof area suitable for PV.

***Assumed Data***

For several important model variables, no data were available from Peabody for each estate and so assumptions were made, as described below.

*Average floor area per unit*.

Data on average floor areas was only available for 12 of the 189 Peabody estates modelled. To generate a value for the remaining estates, data from the English House Condition Survey (EHCS) (CLG 2008) were used. The EHCS data matches average floor areas with number of bedrooms for surveyed English dwellings. A curve of best fit was generated for this data using the statistical package SPSS, to generate the following equation expressing floor area as a function of number of bedrooms

$$\text{Floor Area} = 29.516 \times e \wedge ( 0.366 \times \text{Number of Bedrooms})$$

It was expected that this function would over-estimate floor areas for Peabody stock, as the greater than average competition for land in the London area relative to the English average, would be likely to lead to smaller than average homes. Checking the function against figures for the Peabody estates where floor area data was available, supported this hypothesis, with the discrepancy being larger for the larger estates. To correct for this discrepancy, a constant K was introduced into the above equation, giving

$$\text{Floor Area} = 29.516 \times e \wedge ( K \times 0.366 \times \text{Number of Bedrooms})$$

A value for K was calculated using data from the English House Condition Survey regional report (CLG 2006), that gives figures for average floor areas for private and social rented homes for London and for England. This data was used to create an exponential curve of best fit for the relationship between average floor areas in England and average floor areas in London using SPSS. A value for K of 0.92 was produced from this curve.

*Average window area per unit*

Average window areas were estimated using equations from SAP 2005 (BRE 2006a), which give figures based upon year of construction, total floor area (TFA) and type of dwelling (table 1.2). For each estate an average was calculated for flats and any houses on the estate, and these figures were used to create an overall average. For estates with a varied age profile, the figures for 1950-1966 were used.

| Age Band | House or Bungalow: Window Area (WA) in square metres | Flat or Maisonette: Window Area (WA) in square metres |
|---|---|---|
| Before 1950 | WA = 0.1220 TFA + 6.875 | WA = 0.0801 TFA + 5.580 |
| 1950-1966 | WA = 0.1294 TFA + 5.515 | WA = 0.0341 TFA + 8.562 |
| 1967-1975 | WA = 0.1239 TFA + 7.332 | WA = 0.0717 TFA + 6.560 |
| 1976-1982 | WA = 0.1252 TFA + 5.520 | WA = 0.1199 TFA + 1.975 |
| 1983-1990 | WA = 0.1356 TFA + 5.242 | WA = 0.0510 TFA + 4.554 |
| 1991-1995 | WA = 0.0948 TFA + 6.534 | WA = 0.0813 TFA + 3.744 |
| 1996-2002 | WA = 0.1382 TFA – 0.027 | WA = 0.1148 TFA + 0.392 |
| 2003 onwards | WA = 0.1435 TFA – 0.403 | WA = 0.1747 TFA – 2.834 |

*Table 1.2 Equations for average window areas*

*External wall area per unit*

The approach taken follows that used by Boardman et al (2005), with wall area for a dwelling given as:

$$\text{Total wall area} = \text{perimeter} \times \text{storey height (2.5m)} \times \text{number of storeys per dwelling}$$

Dwellings are assumed for simplicity to be square, making the perimeter 4 × √ (floor area / number of storeys). The number of storeys per dwelling is estimated based upon the average total floor area (TFA) for the estate. It is assumed that dwellings have one storey if TFA < 70, two storeys if 70 ≤ TFA < 100, and three storeys if TFA ≥ 100, based upon the number of storeys in dwellings on Peabody estates where floor areas are known.

The total exposed external wall area (including windows and doors) is then calculated from the above estimate by multiplying by a correction factor of 0.4 for flats and mid-terrace houses and 0.7 for end-terrace houses. It is assumed here for simplicity that all Peabody houses are terraces, as only a small fraction are either detached or semi-detached. Furthermore, it is assumed that 75% are mid-terraces and 25% are end-terraces, based upon average terrace lengths of around eight units indicated by estate descriptions in Peabody's property portfolio. This gives an average correction factor for houses of 0.475.

External exposed wall area (excluding windows and doors) is then the total exposed external wall area subtracted by window area (generated using SAP 2005 equations, described above) and door area (1.85$m^2$ per door, assuming one door for flats, two doors for houses (BRE 2006)).

## 1.3. Refurbishment Strategies

It is assumed that Peabody's Decent Homes programme continues to 2010. This is currently being delivered by Peabody through two refurbishment programmes running in parallel, DECENT (focussing on internal improvements) and SOUND (focussing on external improvements). It is then assumed that Decent Homes measures are followed by one of four possible refurbishment approaches (Base, Fabric, Communal, Renewables) from 2011 to 2030. The rationale of each refurbishment approach and the implications for stock refurbishment are described in this section.

### *Decent Homes*

Any estates with Old (as defined in 1.1) heating services have gas central heating supplied by condensing combination boilers installed to replace room heaters. Electric storage heaters on these estates remain installed, as is current Peabody practice. This leads to an assumed 5% of homes on estates with Old heating services retaining electric storage heaters after Decent Homes work is complete.

Peabody experience to date is of a small minority of residents refusing central heating installations, creating the need to install central heating at the end of their tenancy. The Peabody Energy Model uses the simplifying assumption that no refusals take place, and that all gas room heaters are replaced with gas central heating by the Decent Homes programme. It is assumed that any estates for which double-glazing installation is planned as part of Peabody's SOUND programme of external fabric works receive the improvement during the year of the Decent Homes improvements through the DECENT programme. Estates with existing communal heating receive thermostatic radiator valves (TRVs) as a result of the Decent Homes improvements, improving the assumed efficiency of the communal boilers.

### *Base approach*

After the Decent Homes programme is complete in 2010, no further changes are made to the types of energy supply systems installed on Peabody estates. Gas boilers, electric storage heaters and communal boilers are replaced on a like-for-like basis to 2030. This brings about an improvement in efficiency as older boilers are gradually replaced by more-efficient modern boilers.

Peabody estimates that almost all estates will be double-glazed by 2050 under current projected plans and budgets. It is therefore assumed that around half of the estates requiring double-glazing after the Decent Homes programme is complete will receive it by 2030. Peabody's plans are for estates to receive double-glazing if a visit as part of Peabody's stock maintenance programme reveals that windows need to be replaced. As a result, the particular estates that will receive this measure to 2030 are at present unknown. Double glazing was therefore allocated randomly to estates needing the improvement, subject to the condition that 50% of estates are treated. The work was carried out in the year allocated to the estate for fabric improvements, described below.

***Fabric***

A package of measures to improve the building fabric and some services is applied to each estate through a one-off visit after 2010. The selection of measures and U-values achieved by insulation are based upon the enhanced Fabric package considered by Dwyer (2007). Measures are applied to each estate where required from a package consisting of:

| | |
|---|---|
| Solid wall insulation | applied externally on any estates with uninsulated solid walls, except for listed estates or estates in conservation areas, to achieve a U-value of 0.38 W/m$^2$K. |
| Double-glazing | wooden-framed units installed giving a U-value of 1.6 W/m$^2$K. |
| Extractor fans | low energy-use extractor fans installed in the kitchen and bathroom where required (for 80% of dwellings on estates with Old gas heating systems). |
| Thermostatic radiator valves (TRVs) | five TRVs installed per unit where required (for 75% of dwellings on estates with Old gas heating systems). |
| Replacement of storage heaters with gas boilers | condensing gas combination boilers installed in place of electric storage heaters wherever present. Estates treated are current all-electric estates, part-electric estates and estates with Old heating installations. |
| Heat meters and improved controls | Individual heating controls installed on estates with existing communal heating so that residents can be billed according to use, providing an assumed improvement in system efficiency as less heat is wasted. |

*Table 1.3 Description of fabric measures*

The exception to this single visit approach is for listed estates or estates in conservation areas. In addition to the single visit where the measures from the list above are applied, it is assumed that from 2011 to 2030 internal wall insulation, extractor fans and floor insulation (for ground floor units) are installed in void dwellings as they become available. Internal wall insulation is assumed to achieve the same U-value as external wall insulation of 0.38 W/m$^2$K. Floor insulation is assumed to achieve a U-value of 0.22 W/m$^2$K.

In all scenarios, estates are visited for single-visit improvements over the period 2011 to 2024, so that the benefits of refurbishment have been realised by 2025, the year when progress is assessed against the carbon emission reduction target set by the Greater London Authority (GLA). The order of works planned in Peabody's SOUND refurbishment programme specifies the order of visits to estates.

For the SD and PD scenarios, a fraction of estates are assumed to be in "Low Carbon Zones", and receive refurbishment at no cost in the period 2011 to 2015. This is an approach to funding and delivering refurbishment advocated by Boardman (2007) to combat fuel poverty and reduce carbon emissions. This one-off refurbishment covers all fabric measures, and in addition, covers the cost of district heating connections, heat pumps and solar thermal installations where these are considered as part of alternative refurbishment approaches.

An Advanced Fabric approach is also considered as an alternative option, where improvements follow the approach of Passivhaus refurbishment (Energie Institut 2007) to achieve a very low space heating demand and a high level of airtightness. This approach assumes that all estates are treated and brought up to a very high standard, even those estates which currently have insulated walls. For ground floor units, or estates where external insulation is not possible, this approach requires the decanting of residents so that internal insulation improvements can be carried out. Where homes are treated the following measures are installed: thick external/internal wall insulation (U-value 0.15 W/m$^2$K); triple-glazing (U-value 0.8 W/m$^2$K); mechanical ventilation with heat recovery; floor insulation (U-value 0.22 W/m$^2$K); improvements to reduce losses through infiltration and cold bridges.

***Communal***

This approach includes the measures described for the Fabric approach above, and adds the installation of communal heating systems on suitable estates. It is assumed that communal improvements take place at the same time as fabric measures, during the period 2011 to 2024. An exception to this is for estates receiving CHP installations that fall in Low Carbon Zones: in this case the year of fabric works is moved forward, taking place by 2016, whilst the CHP installation date remains unchanged. This report also considers the option of carrying out all Fabric improvements by 2016 — where this is done, the year of Communal improvements is unaffected.

Technical constraints such as lack of space for a CHP plant room or for pipework to deliver hot water are likely to make it impractical to install communal heating on a number of Peabody estates (Rickaby Thompson Associates 2003), although the particular estates to which these constraints would apply is unknown. As a result, it is assumed that only 80% of Peabody estates are suitable for communal heating, with the 20% of estates that are unsuitable chosen at random.

Where a connection to an external district heating scheme is assumed to be possible, this is carried out (in preference to CHP on estates with communal heating potential). For six Peabody estates (Abbey Orchard, Pimlico, Tachbrook, Boxley Street, Evelyn Road and Fort Street), a potential district heating connection already exists. For other estates where the possibility of a district heating connection being available over the period to 2030 is unknown, the availability is distributed randomly amongst candidate Peabody estates. Only estates in central London boroughs are considered for district heating, based on research that identified these areas as the most suitable for the technology in London (Greenpeace 2006).

For the SD and PD scenarios, it is assumed that 25% of estates will have the option of connecting to a district heating network, based upon the GLA aspiration of 25% of London's energy coming from decentralised energy by 2025 (GLA 2007). For the KLO and BD scenarios, it is assumed that there is less success in providing district heating in London, so that only 10% of estates have a potential connection. Where a connection is possible, it is assumed that every dwelling on the estate is connected to district heating. Each of these assumptions reflects a significant increase in district heating availability in London, a position taken due to the strong focus being placed by the GLA in developing this infrastructure over coming years (ibid).

For Communal and Communal Potential estates, gas-fired CHP systems are installed where no district heating connection is available. For these estates, the CHP is sized to meet the base hot water demand for the estate throughout the year. This is due to the assumption of either a low heat load, due to insulation improvements, or a heat load gradually reducing to a low level (on estates where void dwellings are insulated as they become available). Based upon Peabody experience, this makes the CHP system best sized to meet hot water demand.

An alternative approach explored in chapter five of this report is for estates that do have uninsulated solid walls to remain uninsulated, and for CHP to be installed that is sized to meet the majority of heat and hot water demand (in this case, the CHP plant would not run in the summer).

Based upon guidance for CHP sizing and running times (CIBSE 1999; Hinojosa, Daya et al. 2005), it is assumed that CHP meeting the majority of the heat load runs for 4000 hours a year, and is sized to supply 69% of total heat and hot water demand, whilst CHP running year-round runs for 6200 hours a year, being sized to provide for the hot water demanded on that estate.

Two CHP technologies, miniCHP (serving small clusters of homes) and microCHP (serving individual homes) have not been considered for this research. In the case of microCHP, this is because the technology is unlikely to be suitable for the great majority of Peabody homes, as it is best-suited for larger homes with a high, consistent heat demand (Carbon Trust 2007). MiniCHP is an emerging technology that may have application on particular estates or parts of estates in Peabody's portfolio, but identifying such sites was beyond the scope of this research.

***Renewables***

This approach matches the Communal approach, with the following additions: solar thermal panels are installed to supply hot water to top floor flats and houses (except on estates that are listed or in conservation areas); solar photovoltaic (PV) panels are installed on all available appropriately-oriented roof space, with priority being given to solar thermal. Solar thermal panels are installed on south-facing roofs only, whilst solar PV is also considered for west-facing and east-facing roof space.

Ground source and air source heat pumps are not considered as part of the original Renewables approach, but their potential impacts are also explored in this research. It is assumed that both technologies are installed in combination with over-size radiators, due to the disruption and extra costs involved in installing underfloor heating in existing dwellings. Over-size radiators in themselves may prove disruptive to residents, especially in smaller homes, so concerns about loss of space may limit their application in practice.

Ground source heat pumps are considered for houses with gardens on Peabody estates. This assumption is likely to represent an upper limit on their applicability, as many sites will either not be suitable for a borehole, due to underground services or unfavourable ground conditions, or be inaccessible for a drilling rig. Air source heat pumps are considered on estates with small dwellings, where the average floor area is below 60m$^2$ (WWF 2008) and are not considered on estates in conservation areas. To avoid competition between servicing options, it is assumed that solar thermal panels are not installed where heat pumps or communal heating are installed.

Communal biomass boilers are also considered as an alternative to gas-fired CHP in chapter five of the report. It is assumed for this research that woodchip is used as a fuel, as was the case at Peabody's BedZED estate, but wood pellets could be an equally effective choice of fuel. The same approach to sizing and running hours is employed as for gas-fired CHP, and they are used in combination with gas-fired backup boilers. The extent to which it will be possible for Peabody to install biomass boilers over coming years is still unclear, as concerns about particulate pollution may lead to limits on their use in central London.

Micro-wind turbines are not considered in the Peabody Energy Model, due to evidence of poor performance in urban areas (Booth 2007). However, there is evidence of micro-wind technologies performing well on high-rise buildings, so there could be a case for installing micro-wind on the two high-rise blocks managed by Peabody.

Biomass CHP is not considered in the model as it is not yet a mature technology on the scale required for Peabody estates (Renewables Advisory Board 2007). Its application is considered where the prospects for making Peabody estates zero-carbon are assessed, and it is assumed there that Biomass CHP is fuelled by woodchip and has the same heat and electrical efficiency as gas-fired CHP.

Off-site renewable measures, such as funding the installation of off-site wind turbines, have not been considered for this research. This is due to the focus of this research on what can be achieved through improvements to the Peabody stock itself. The results from this analysis are intended to inform the broader debate around the extent to which carbon reductions from housing should be achieved on-site through demand reduction and micro-generation, or off-site through decarbonising the energy system.

## 1.4. Estate Energy Demand

The modelling used BRE's Domestic Energy Model (BREDEM) as a starting point (BRE 2001), which estimates domestic energy demand as a function of floor area and number of residents, and has been widely used in similar research. Following the BREDEM approach, energy demand was broken up into five distinct categories: heat, hot water, lighting, cooking and (other) electricity.

Resident demand for energy is likely to change over coming years, as it is subject to a number of potentially strong influences such as changing consumption patterns, high fuel prices, or concerns about climate change. This is considered in the model by modifying annual energy use for each category by a multiplier so that changes in demand for energy can be quantified. A mulitplier of 1 represents a level of energy demand equal to that derived from the physical-based model, a multiplier below 1 represents a lower level of demand and a multiplier above 1 a higher level of demand. The values chosen are specified for each scenario considered in the research.

***Heating***

Modelled demand for energy for heating is based upon the built form of the estate and an assumed heat demand figure per unit area. Base heat demand for dwellings on each estate is calculated using figures for kWh per square metre per annum for different dwelling types (table 1.4). The model assumes that for a given dwelling type, heat demand increases linearly with floor area. Flats and houses were considered separately, so on estates containing both dwelling types, an average heat demand based upon their relative proportions was calculated.

The assumptions for heat demand per square metre are derived from the Community Domestic Energy Model (CDEM), an implementation of the BREDEM model applied to different dwelling types developed at De Montfort University (Firth 2007). Model outputs were available from the CDEM for "average" flats and detached houses, based upon assumptions of the physical properties of typical blocks of flats or streets of houses. As Peabody houses are rarely detached and are typically either semi-detached or in terraces, values for Peabody houses were estimated by using a figure mid-way between those available for flats and detached houses (table 1.4).

| | Base estimate (kWh/m2) | Insulated wall reduction (kWh/m2) | Double glazing reduction (with no wall insulation) (kWh/m2) | Floor insulation reduction (kWh/m2) |
|---|---|---|---|---|
| Flats: Pre Decent Homes | 141.1 | 59.7 | 25.3 (23.1) | |
| Flats: Post Decent Homes | 123.2 | 54.8 | 23.2 (21.2) | 5.1 |
| Flats: Modern | 45.5 | | | |
| Houses: Pre Decent Homes | 163.5 | 66.9 | 25.2 (24.8) | |
| Houses: Post Decent Homes | 146.1 | 62.8 | 23.6 (23.3) | 6.0 |
| Houses: Modern | 57.3 | | | |

*Table 1.4 Heat demand per unit area for different dwelling types*

Due to evidence that physical-based domestic energy models often over-estimate the extent of heat demand savings due to insulation improvements (Milne and Boardman 2000; Hong, Oreszczyn et al. 2006; Sanders and Phillipson 2006), it was assumed that not all of the benefits suggested by the original CDEM figures were realised. This was done by calculating the reduction in heat demand for each dwelling type relative to the most energy inefficient dwelling of the same built form (pre-Decent Homes, single glazed, uninsulated solid walls), and assuming that only 85% of this reduction was realised. The 85% figure is based upon the estimate put forward by Milne and Boardman (2000) and Sanders and Phillipson (2006) of 15% of the benefit of insulation improvements being "taken back" by householders through increased temperatures. This is a relatively conservative assumption, as research has identified up to 50% of expected demand reduction not being realised when all factors are considered (Sanders and Phillipson 2006). The impacts of fabric improvements having an even lower impact were therefore considered through a sensitivity analysis.

It is assumed that the level of heat demanded by Peabody residents is equal to the level given by the CDEM model in the base year 2006. This judgement is based upon evidence from a survey of

Peabody residents in 2007, which indicated that the hours of assumed heating use in the BREDEM model are a reasonable approximation for Peabody residents' heating use.

***Hot water***

Hot water demand is assumed to be a function of the number of residents in a dwelling. In the BREDEM model, daily hot water demand ($Q_u$) for an average dwelling, measured in GJ, is modelled by the equation

$$Q_u = 8.64 \times 10^{-5} \times ( 78 + 52 N )$$

where N is the number of occupants (BRE 2001).

Research conducted for the UK government's Department of Trade and Industry found that domestic hot water demand varied linearly with number of occupants, and that demand had increased since the BREDEM equation was developed (DTI 2005a). As a result, the following alternative equation was proposed

$$Q_u = 8.64 \text{ x } 10^{-5} \times ( 51.85 / 25 \times 40 N )$$

This has been used for the Peabody Energy Model, and it is assumed that it applies equally to hot water use in the base year 2006. Losses incurred in hot water supply were calculated for each estate using data from Peabody's stock condition database on the hot water systems installed, and equations from the BREDEM model. There is no linkage in the model developed for this research between the level of losses from hot water systems and space heating demand, due to the extra complexity involved in taking this into account. As levels of losses do not differ greatly between the four principal refurbishment approaches considered, this is unlikely to have a significant impact on results.

***Lighting***

Energy use for lighting is assumed to be a function of the floor area of Peabody dwellings along with the proportion of low energy bulbs fitted. It was modelled using a modified version of the equation given in SAP 2005 (BRE 2006), which gives an equation for lighting energy use as

$$E_L = E_B \times TFA \times C_1 \times C_2 \text{ kWh / year}$$

where:

$E_B$ = 9.3 kWh/$m_2$
TFA is the total floor area, $m^2$
$C_1$ = 1 – 2/3 x 3/4 × $N_{LE}$ / N (where N is the number of fixed lighting outlets, $N_{LE}$ the number of fixed outlets fitted with low energy bulbs
$C_2$ is a correction factor to take into account the effects of daylighting

Savings due to energy efficient lighting are modelled using the constant $C_{1;}$ the fraction 3/4 represents the assumed fraction of energy saved by using a compact fluorescent lamp (CFL) in place of an incandescent bulb; 2/3 represents the fraction of lighting energy consumption coming from fixed outlets. It is assumed in the SAP 2005 equation that CFLs are only installed in these fittings, not in movable lamps.

Under all scenarios considered for the model, it is assumed that incandescent bulbs are phased out in the UK (Defra 2007b), so that all lighting is from energy efficient bulbs by 2015. The SD and PD scenarios assume, following Boardman (2007), that CFLs begin to be phased out from 2015 to be replaced with light emitting diodes (LEDs) which are assumed to use $1/20^{th}$ of the energy of conventional bulbs (based on Boardman (2007)).

The SAP equation is inadequate in this context, as it assumes that one third of all lighting demand is still met with incandescent bulbs installed in movable lamps, and that all energy efficient bulbs are CFLs. As a result, the equation has been modified for the Peabody Energy Model, with $C_1$ being redefined as

$$C_1 = 1 - (1/3 \times E_y \times NM_{LE} / NM) - (2/3 \times E_y \times N_{LE} / N)$$

where:
$E_y$ is the fraction of energy saved by an energy efficient bulb in the year y,
$NM_{LE}$ / NM is the fraction of movable lamps fitted with energy efficient bulbs.

For 2006, $N_{LE}$ / N is assumed to be 0.55, based upon results from a survey of Peabody residents at its residents' conference in 2007. $NM_{LE}$ / NM for 2006 is assumed to be 0, in line with the SAP 2005 model. Both $N_{LE}$ / N and $NM_{LE}$ / NM increase linearly to 1 in 2015, based upon the assumption that by that date all lamps are CFLs.

In the SD and PD scenarios, CFLs are phased out for LEDs from 2015, so that LEDs alone are being used by 2030. The KLO and BD scenarios assume a lower take-up of LEDs from 2015, with 20% of light fittings LEDs in 2030 and 80% CFLs.

Although energy used in the home for lighting has declined slightly since the BREDEM model was published in 2001, there is no strong evidence of a decline in the energy service sought from lighting, so it is assumed that the equation described above specifies demand for energy for lighting for 2006.

### *Cooking*

Energy use for cooking is assumed to be a function of the number of residents in Peabody households. It was modelled using the equations from the BREDEM model, which gives annual energy use $E_C$ in GJ is given as

$$E_C = 1.70 + 0.34\,N, \text{ for cooking with electricity}$$
$$E_C = 2.98 + 0.60\,N, \text{ for cooking with gas}$$

where N is the number of occupants. This is translated into energy use for cooking at the estate level with figures from Peabody for average occupancy for each estate and data on the number of gas and electric cookers from Peabody's stock condition database.

Since 2001 when the BREDEM model was published, energy use for cooking has declined by 6% (BERR 2008a). Therefore the base energy use for cooking in 2006 was calculated using the above equations, then by reducing the result by 6%.

### *Other electricity*

Demand for "other" electricity, to provide energy for household appliances is assumed to be a function of both the floor area of a home and the number of householders. An equation from BREDEM was used to model demand for other electricity, which gives electricity for lights and appliances in GJ as

$$E_L = E_{LA} - \text{Energy used for lighting} + \text{Energy used for pumps and fans}$$

where

$$E_{LA} = 4.47 + 0.0232 \times TFA \times N$$

for

TFA = total floor area of a dwelling
N = number of occupants

Energy used for pumps and fans was calculated for each estate based upon the energy supply systems installed on each estate and using data from SAP 2005. The energy used for lighting in this equation is the energy use given by the original SAP 2005 equation for lighting use, reported above.

Since 2001, when BREDEM was published, electricity demand for purposes other than lighting, heating and cooking has increased by 11% (BERR 2008a). This increase was therefore applied to the figure for base demand arrived at using the above equation. Conversely, due to evidence of lower electricity use for social housing tenants (Brandon and Lewis 1999), it was assumed that electricity demand for Peabody homes would be lower than that given in the BREDEM equation. A 10% reduction was applied based upon Peabody experience on its BedZED estate. Taken together these two modifications leave the equation used for electricity demand close to the original BREDEM equation.

***Changes in demand***

Changes in demand beyond 2006 are modelled in three steps. Initially it is assumed that present trends continue to 2010 for each scenario (i.e. no change in demand for lighting, hot water or heating; annual 1.1% reduction in demand for energy for cooking; annual 1.65% increase in demand for "other electricity").

Changes in demand are then considered up to 2016. This is a relatively short period, which is used so that any rapid demand reductions that represent the "low hanging fruit" of energy saving can be captured. Beyond this date, changes in demand are considered up to 2030. In each case an annual percentage change in demand is considered for each energy use.

The values used are specified according to the scenario under question with the values used given in Appendix III. The principles used to determine the values used were: present trends continuing in the KLO scenario; behaviour change leading to reduced energy demand up to 2016 in the SD and PD scenarios; high fuel prices leading to reduced energy demand in the PD and BD scenarios from 2016 onwards.

## 1.5. Fuel use for estates

Energy demand is converted into annual fuel use for each estate using the assumed efficiencies of energy supply systems given in this section.

***Gas Boiler efficiencies***

| Gas heating type | Efficiency in 2006 | Source |
|---|---|---|
| Gas heating: Old estates, pre Decent Homes | 70% | BRE (2006) |
| Gas hot water: Old estates, pre Decent Homes | 63% | BRE (2006) |
| Gas heating and hot water: Old estates, post Decent Homes | 75% | BRE (2006) |
| Gas heating and hot water: New estates | 83% | BRE (2006) |
| New condensing combination boilers | 90% | Dwyer (2007) |

*Table 1.5 Gas boiler efficiencies*

Units without TRVs were assumed to have a 5% reduction in their efficiency for supplying heat (BRE 2006a). As new boilers are installed, a greater proportion of boilers on Peabody estates are condensing boilers, leading to the average efficiency of gas boilers on each estate gradually improving. As a result, by 2018 (after 12 years, the assumed lifetime of a gas boiler) all boilers are 90% efficient.

***Electric heating***

Electric heating systems are assumed to be 100% efficient (BRE 2006a), although efficiency losses are associated with the production and distribution of electricity prior to its arrival in homes (which are accounted for in the emission factors used for electricity). As is the case for gas-fired systems, there are losses associated with the storage and distribution of electrically-heated hot water, calculated using equations from BREDEM (BRE 2001).

***Communal heating efficiencies***

| Boiler Type | Efficiency | Source |
|---|---|---|
| Existing communal boilers, pre Decent Homes | 65% | BRE (2006a) |
| Existing communal boilers, post Decent Homes | 70% | BRE (2006a) |
| New communal boilers & existing communal boilers, post Fabric package | 85% | Dwyer (2007) |
| Biomass boilers | 85% | Renewables Advisory Board (2007) |
| CHP | 50% heat, 28% electricity | Dwyer (2007) |
| Biomass CHP | 50% heat, 28% electricity | Dwyer (2007) |

*Table 1.6 Communal heating efficiencies*

## 1.6. Micro-generation

***Solar Thermal***

It is assumed that $4m^2$ of solar thermal panels is installed for each house/bungalow and, following the approach of Dwyer (2007), for top floor flats where south-facing roof space is available. The annual output per square metre is assumed to be 400kWh (based on London Renewables (2004) and Croxford and Scott (2006)). As discussed above, solar thermal panels are not installed on listed estates or estates in conservation areas.

Installations are also limited by the availability of suitable roof space. It is assumed that total roof space for an estate is equal to the total footprint of the estate's buildings. This is calculated as:

$$\text{Total roof space} = \frac{\text{number of dwellings} \times \text{average dwelling floor area}}{\text{average number of storeys on estate}}$$

For many Peabody estates, data was available for total roof space from research carried out by the consultants Whitby Bird in 2001 into the potential for solar PV on Peabody estates (Whitby Bird & Partners 2001). This data gives areas in square metres for roof space broken down by roof type and orientation (flat, south-facing, east-facing, west-facing or north-facing). Where available, this data was used in preference to an estimate (although in a minority of cases it was rejected in favour of an estimate using the above equation, where the Whitby Bird data provided a value that was more than 2/3 of the value of the estimated roof space, indicating a likely error).

For estates with pitched roofs, it is assumed that 25% of total roof space is oriented so as to be suitable for solar thermal (between south-west and south-east). Then 70% of this area is assumed to be free of obstructions and shading so as to be suitable for solar panel installation (Whitby Bird & Partners 2001). For estates with flat roofs, 50% of the roof area is assumed to be available for solar panels (ibid).

***Photovoltaic Panels***

Photovoltaics panels (solar PV) are subject to the same planning and physical constraints as solar thermal panels above. However, to identify the full extent of reductions achievable through their use, it is assumed that they can be installed on south, east and west facing roof space and on flat roofs. It is assumed that priority is given to solar thermal installations, and that solar PV is then installed to fill the available suitable roof space. Polycrystalline panels are used, with an assumed net output (after inverter losses) of 90kWh/m$^2$ on flat roofs, 88kWh/m$^2$ on south-facing roofs and 75kWh/m$^2$ on east and west facing roofs (ibid).

***Ground Source Heat Pumps***

Where installed, ground source heat pumps (GSHPs) are assumed to be installed with over-sized radiators, due to the disruption and high costs involved in converting dwellings to underfloor heating. It is assumed that they provide all of the heat and hot water requirements of the dwelling. The coefficient of performance (COP) is assumed to be 2.4 for heat and 1.68 for hot water (BRE 2006).

***Air Source Heat Pumps***

Air source heat pumps (ASHPs) are treated in the same way as GSHPs, although they are only considered on estates with small homes (average size below 60m$^2$ (WWF 2008)), and are not installed on estates in conservation areas. The coefficient of performance (COP) is assumed to be 1.88 for heat and 1.31 for hot water (BRE 2006).

## 1.7. Carbon emission factors

Base carbon emission factors are given below (table 1.7). Woodchips used for biomass boilers were assumed to be carbon neutral, as although there are clearly emissions associated with the transportation and processing of the fuel, these supply chain emissions are not considered for other conversion factors, and so for consistency, have not been considered for biomass. The emissions factor for district heating is based upon data provided by Peabody on an existing district heating scheme in London.

Changes in emission factor assumed are given in table 1.8. For all scenarios, the change for grid electricity up to 2010 is based on projections from the Market Transformation Programme (MTP 2007). Beyond this date, further changes are assumed to differ by scenario. For the KLO and BD scenarios, the reductions projected by the Market Transformation Programme to 2020 are assumed, and linearly extrapolated on to 2030. For the SD and PD scenarios, greater reductions are assumed, so that the carbon intensity of electricity falls to around half its 2006 level by 2030. The figure used for 2030 is based upon the low estimate used by the Renewables Advisory Board (2007). The assumed reduction of approximately 50% on current levels, matches the reduction called for in London's Climate Change Action Plan as a step required for London to achieve its carbon reduction targets (GLA 2007). Whilst representing substantial change relative to the present day, this assumption is still relatively conservative when compared to the near-total grid decarbonisation by 2030 called for by the Committee on Climate Change (Committee on Climate Change 2008).

| Energy Source | Emissions factor 2006 (kg$CO_2$ /kWh) | Source |
|---|---|---|
| Gas | 0.204 | Defra (2007c) |
| Electricity | 0.527 | Defra (2007c) |
| Displaced grid electricity | 0.568 | BRE (2006) |
| District heating (heat supplied) | 0.33 (for gas used only) | Based on Peabody experience |
| District heating (heat supplied) | 0.13 (net emission factor, considering displaced grid electricity) | Based on Peabody experience |

*Table 1.7 Base carbon emission factors*

For district heating, the KLO and BD scenarios assume no change in the carbon intensity of the fuel used (which is assumed to continue to only be natural gas). The SD and PD scenarios assume a declining carbon intensity of heat from district heating due to increased use of biomass and biogas as a fuel. No known projections for take-up of these fuels for district heating in London exist, so an optimistic assumption was made that by 2030, one third of the fuel used for district heating is renewable.

The overall carbon emissions associated with district heating also take into account the carbon emission reductions associated with displacing grid electricity, which decline in each scenario up to 2030 as more renewables supply the grid. This has the impact of making the carbon emission factor associated with district heating greater than it would be otherwise.

| Energy source | Scenarios | Period | Change per year ($kgCO_2/kWh$) | Source |
|---|---|---|---|---|
| Electricity | ALL | 2006–2010 | -0.00175 | Based on MTP (2007) |
| Electricity | KLO & BD | 2011–2030 | -0.0099 | Based on MTP (2007) |
| Electricity | SD & PD | 2011–2030 | -0.01745 | Based on GLA (2007) |
| District Heating | SD & PD | 2006–2030 | -0.0046 | Assumed |

*Table 1.8 Changes in carbon emission factors*

The resultant carbon intensity of the energy sources considered is shown in figure 1.2. The graph shows that from 2028, electricity has a lower carbon emission factor than gas in the SD and PD scenarios, illustrating the potential for grid decarbonisation to reduce the relative effectiveness of gas as a low-carbon fuel.

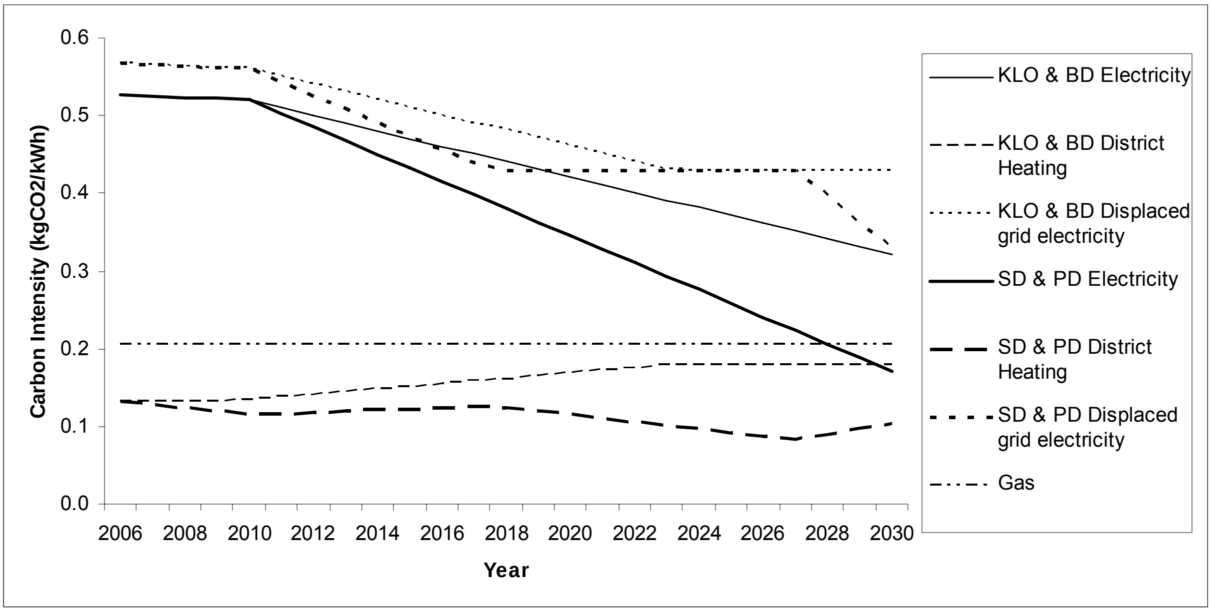


*Figure 1.2  Carbon Intensity of electricity, gas and district heating*

### *Displaced Grid Electricity*

The approach taken to displaced grid electricity is worthy of particular attention due to the conflicting approaches found in existing literature. This assumption has a significant impact on model results, as the sensitivity analysis chapter in the report demonstrates, and as has been observed in previous research in this area (UK Green Building Council 2008).

For the base year 2006, it is assumed that where electricity is generated by solar PV or CHP and exported to the grid, net carbon emissions are reduced by 0.568 kg $CO_2$ for each kWh generated (BRE 2006). This figure is greater than the grid intensity assumed for electricity use (0.527 kg $CO_2$ per kWh), as it is based upon the principle that the use of the more carbon-intensive marginal plant used to provide for extra demand (coal and gas fired power stations) is being reduced. As a result, an estate where fossil fuels are used (for example, gas as fuel for condensing boilers) can still achieve zero net carbon emissions if sufficient on-site generation takes place.

One issue considered by this research is the potential for the carbon intensity of grid electricity to approach or reach zero. If the grid produces zero-carbon electricity, a reduction in net emissions for any electricity generated would no longer be appropriate, as any displaced grid electricity would be from a zero-carbon source.

Where a pathway from the original grid carbon intensity of 0.527 kg $CO_2$ per kWh to zero is assumed, there is therefore a need to put forward a pathway for the carbon intensity of displaced grid electricity that arrives at the same end point (zero) at the same time. This consideration gives rise to a number of approaches for accounting for the carbon intensity of grid electricity (figure 1.3).

One possible approach would be to assume that displaced electricity has the same carbon intensity as any electricity used. This approach was rejected as it does not take into account the extra benefit achieved through micro-generation of displacing the more carbon-intensive marginal capacity of the grid.

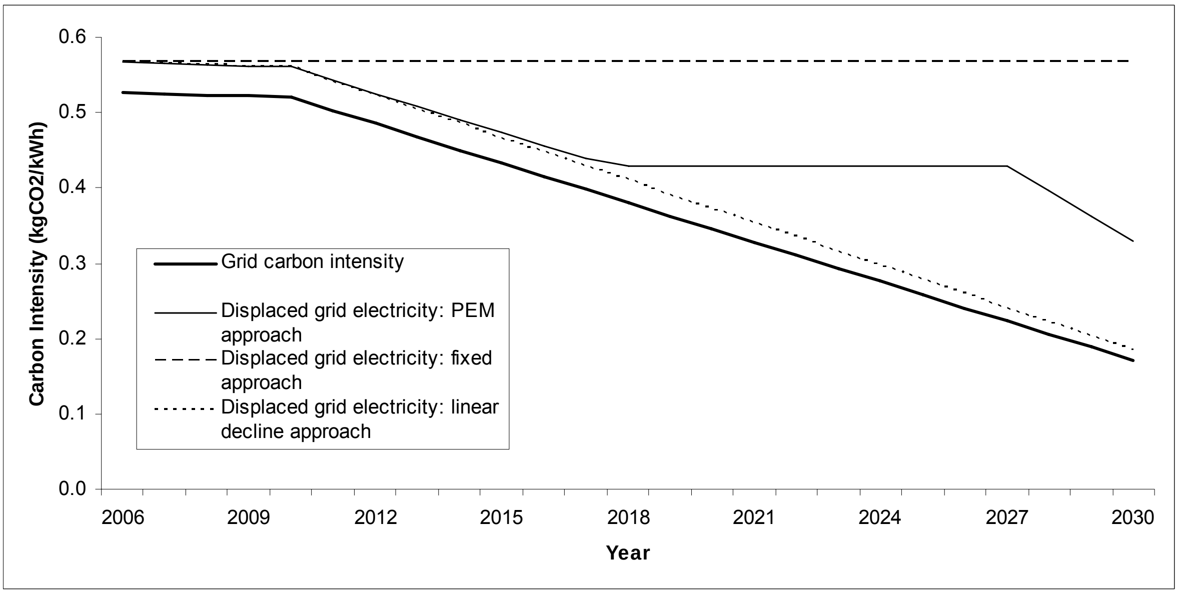


*Figure 1.3 Approaches to displaced grid electricity*

A similar approach is to simply assume that the carbon intensity of displaced grid electricity declines linearly towards the same zero end-point. This approach was rejected as it was considered that it did not accurately capture the nature of the carbon intensity of displaced electricity. Once a point is reached where the marginal plant supplying the grid is the most efficient combined cycle gas-turbine power stations, further input of renewables into the grid over the following years is unlikely to provide further reductions on the carbon intensity of displaced electricity, as the marginal plant would still be gas-fired power stations.

Another approach that was rejected was assuming that the carbon intensity of grid electricity does not change at all, an assumption used in other research in this area (Renewables Advisory Board 2007). This is not consistent with either the reduction of emissions associated with marginal plant as generation through gas-fired power stations replace coal, or with the possibility of a zero carbon grid.

Therefore an approach was taken where the carbon intensity of displaced electricity initially declines at the same rate as for grid electricity, until it reaches the value of 0.43 kg $CO_2$ per kWh, the figure assumed for efficient gas-fired power stations (Defra 2007c). It then plateaus as these power stations remain the source of marginal supply, despite further renewables being used to supply the grid.

Assuming a pathway to a zero-carbon grid, at some point the displaced electricity carbon intensity must start declining again, as a qualitative change to the supply of electricity begins to take place. There is little research done to date on how this process might happen, although the theoretical possibility has been discussed in the Zero Carbon Britain report (CAT 2007). The Peabody Energy Model assumes that when the grid has a carbon intensity of 0.225 (notionally 50% from combined cycle gas-fired power stations, and 50% from zero-carbon sources), this change commences, starting a linear decline towards zero carbon electricity.

Although this approach is based on some simple assumptions on the nature of electricity supply in the context of a substantial proportion of grid electricity coming from zero-carbon sources, it is put forward as a more realistic approach than either the “fixed” approach (assuming no changes in the carbon intensity of displaced grid electricity), or the “linear decline” approach (assuming a linear pathway towards eventual zero carbon emissions). The impacts of using the latter two approaches were however considered through sensitivity analysis in chapter three of this report.

## 1.8. Fuel costs

***Unit costs and standing charges***

Gas and electricity are typically sold at a higher unit cost for an initial band of units (usually 5860 kWh for gas, 900 kWh for electricity), then a lower unit cost. To incorporate this efficiently within the Peabody Energy Model, gas and electricity costs were modelled using a proxy standing charge (DTI 2006), given by the equation

$$\text{Proxy standing charge} = U \times ( C_1 - C_2 )$$

where U is the usage in kWh for the initial band of units, $C_1$ is the unit cost for these units, and $C_2$ is the unit cost of subsequent units. Costs are then calculated as the proxy standing charge plus any usage multiplied by $C_2$.

The proxy standing charge approach provides accurate results as long as the threshold usage level is exceeded. This is likely to be the case for all dwellings using gas except for where homes have gas cookers only (for example, after individual gas boilers are removed in favour of communal heating). For these dwellings, it is assumed that no standing charge applies and all gas use is charged at the higher initial rate.

Values for base proxy standing charges (table 1.9) and gas and electricity costs (table 1.10) were calculated using data on October 2008 costs from British Gas (for gas) and EDF Energy (for electricity). These suppliers were used since British Gas and EDF were the suppliers in the London area prior to energy supply being opened up to competition, and are therefore more likely than other suppliers to be used by Peabody residents. For the year 2006, where average annual fuel costs are £581, the proxy standing charge totals £151, equating to 26% of average resident costs.

Information on price increases from 2007 to 2008 from the Energylinx website (Energylinx 2008) were used to convert these prices to 2007 levels, then information from BERR on changes in gas and electricity costs from 2006 to 2007 (BERR 2008b) was used to convert prices to 2006 levels. Price conversions were based upon annual average consumption figures from BERR of 3300kWh for electricity and 18000kWh for gas (BERR 2008b).

| Fuel | Proxy standing charge | Source |
|---|---|---|
| Gas / District heating / communal heating | £100.50 | British Gas (2008), BERR (2008b), Energylinx (2008) |
| Standard electricity | £50.50 | EDF (2008), BERR (2008b), Energylinx (2008) |
| Economy 7 electricity | £63.30 | EDF (2008), BERR (2008b), Energylinx (2008) |

*Table 1.9 Proxy standing charges*

Where Peabody buys gas and electricity (on estates where combined heat and power is installed), it is assumed that a bulk purchase arrangement can be made with a utility company so that Peabody pay a fixed rate per unit used, without incurring standing charges. At present, Peabody has such an agreement for gas and electricity supply to estates, and the costs assumed were based upon these figures. Despite having a higher unit rate in the case of gas, this assumption can give Peabody an overall saving on purchases of gas and electricity relative to residents as, unlike Peabody residents, it pays no standing charges.

| Fuel | Cost 2006 (£/kWh) | Source |
|---|---|---|
| Gas | 0.021 | British Gas (2008), BERR (2008b), Energylinx (2008) |
| Standard electricity | 0.088 | EDF (2008), BERR (2008b), Energylinx (2008) |
| Economy 7 (day) | 0.095 | EDF (2008), BERR (2008b), Energylinx (2008) |
| Economy 7 (night) | 0.038 | EDF (2008), BERR (2008b), Energylinx (2008) |
| Gas tariff for initial units | 0.036 | British Gas (2008), BERR (2008b), Energylinx (2008) |
| Peabody gas | 0.023 | Based on British Gas (2008), BERR (2008b), Energylinx (2008) and experience at Peabody |
| Peabody electricity | 0.086 | Based on EDF (2008), BERR (2008b) and experience at Peabody |
| Peabody biomass | 0.025 | Renewables Advisory Board (2007) |

*Table 1.10 Base fuel costs*

***Sales to residents***

For all sales of energy to residents, it is assumed that the sale price cannot leave residents with higher bills than if they are purchasing gas or electricity from the grid, following current practice used in billing residents by Peabody. Furthermore, in order to identify the most cost-effective approach from Peabody's perspective, it is assumed that both the cost of heat and electricity are set at the maximum possible level, so that residents pay an equivalent amount to Peabody as they would to a utility company.

The cost for heat from communal heating for residents is the cost per kWh of delivered heat (for space heating and hot water), not the cost per kWh of gas consumed, as is typically the case where individual gas boilers are used. As gas boilers are not 100% efficient, units of heat can be sold at a marginally higher price than units of gas, without leaving residents worse off overall. Assuming that gas condensing boilers are installed with an efficiency of 90%, the unit price of gas (£0.021, from table 1.10) is initially multiplied by 100/90 to give a maximal unit price for heat sales that takes this into account.

The sale price for heat is further modified by considering that after communal heating is installed, residents are likely to continue to use gas cookers in their homes. As the resulting gas use would all be charged at the higher initial unit rate, residents receiving communal heating would be worse off overall by the approach to pricing described above (paying the same for heat and hot water, but more for cooking). It is therefore assumed that heat is sold to residents with a 10% discount on the maximum possible rate, which leaves the overall unit cost for heat the same as that assumed for gas (table 1.11). This assumption leaves residents with overall costs that are broadly unchanged after receiving a communal heating connection. Electricity sales are priced at the same level as electricity from the grid.

| Energy Source | Cost 2006 / £/kWh |
|---|---|
| Heat (from Communal or District Heating) | 0.021 |
| Electricity | 0.088 |

*Table 1.11 Prices for energy sales to residents*

### *Changes in fuel costs*

The assumed changes for both standing charges and unit costs are given in table 1.12. Based upon changes in gas and electricity prices in recent years, the proxy standing charge is assumed to stay constant in real terms for gas, and to increase at the same rate as unit costs for electricity.

From 2006 to early 2008 gas and electricity prices have risen substantially. Changes during this period are based upon data from utility companies and BERR (2008b). From 2009 to 2030, changes are based upon assumptions made for each scenario. Fuel price changes for this period are challenging to predict, although most analysts expect prices to increase in real terms. Estimates of possible changes in existing literature include an increase of around 2% per annum for gas (Powry Energy 2007), 1% annual increases for gas and 3% for electricity (BERR 2008c), and annual increases for gas and electricity of between 3.5% and 10% (Croxford and Scott 2006). In recent years changes in gas prices have been accompanied by relatively smaller changes in electricity prices (BERR 2008a).

Annual price increases at the high end of the range given above (towards 10%) were not used for this research due to the substantial rise in fuel prices this leads to by 2030. For example, an annual increase of 7.5% in gas prices from 2008 to 2030 leads to 2030 prices being around five times 2008 levels. Increases on this scale do not fit with any of the defined scenarios, which are not intended to represent extreme changes relative to present conditions. Furthermore, since 1970 gas and electricity prices expressed in real terms have remained within 50% of 1990 prices, which approximate an average price over that period (figure 1.4, based on (BERR 2008a). Therefore, although significant price increases have been projected by many analysts and are considered through scenarios for this research, there is no precedent in recent decades of fuel prices going through a many-fold increase.

Given these issues, the increase in prices for gas and electricity for each scenario were based upon relatively low annual increases (table 1.12). Nevertheless, for the highest fuel price scenario, BD, this led to prices for gas approximately doubling relative to 2008 levels, or nearly tripling relative to 1990 levels. For the KLO and BD scenarios, it was assumed that the recent trend for gas prices to rise at a greater rate than electricity prices continues. For SD and PD, it was assumed that the greater investment in new renewable infrastructure for electricity generation led to electricity prices rising at a greater rate.

For simplicity, a smooth increase in fuel prices is assumed for each scenario to represent the broad long-term trend, although in practice, as the historical record shows, there is likely to be considerable fluctuation in prices around any broad trend over the coming decades. There is a possibility that changing the assumptions on fuel price changes could significantly affect model results for each scenario, so this potential was explored in the sensitivity analysis chapter.

Biomass prices are assumed to increase at the same rate as gas prices, due to competition between the two fuel sources and current practice of offering long-term biomass contracts with prices indexed against those of gas or oil (Welsh Biofuels 2008).

| Fuel | Annual increase in price | Source |
|---|---|---|
| Gas units (2006-2007) | 17% | British Gas (2008), BERR (2008b) |
| Gas units (2007-2008) | 15% | British Gas (2008), BERR (2008b) |
| Electricity units and standing charge (2006-2007) | 6% | EDF (2008), BERR (2008b) |
| Electricity units and standing charge (2007-2008) | 13% | EDF (2008), BERR (2008b) |
| Gas units (2008-2030) | 1% (KLO); 1.5% (SD); 2.5% (PD); 3.5% (BD) | Assumed |
| Electricity units (2008-2030) | 1% (KLO); 2.5% (SD); 3.5% (PD); 3% (BD) | Assumed |
| Biomass (2006-2030) | As for gas | Assumed |

*Table 1.12 Annual Changes in fuel costs*

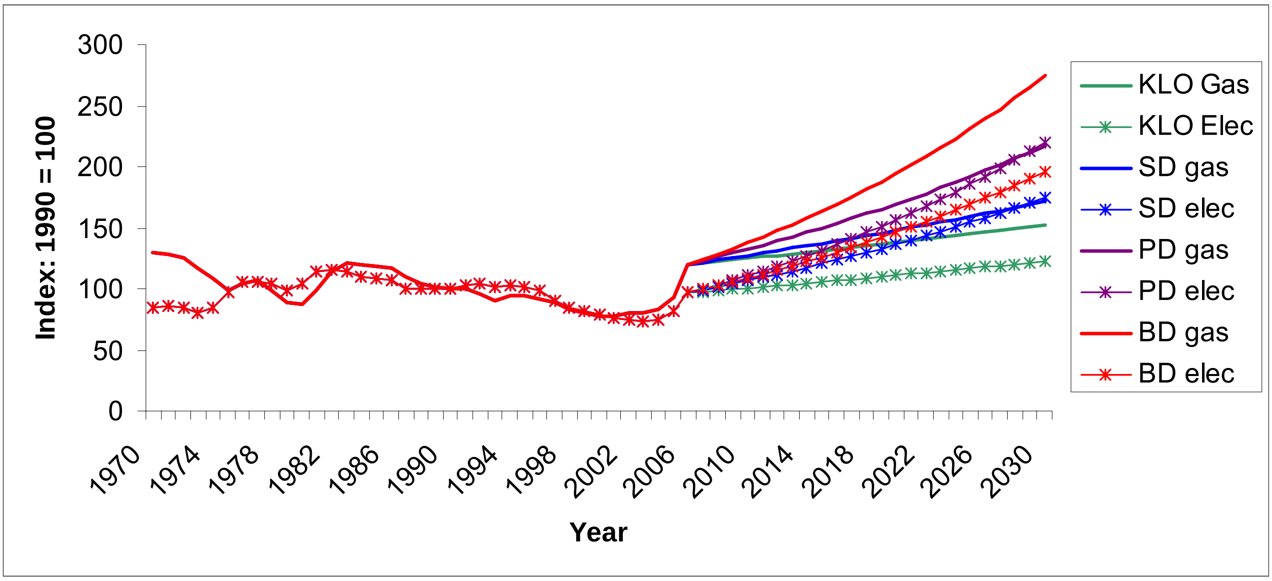


*Figure 1.4 Historical and scenario-specific fuel prices relative to 1990 levels*

## 1.9. Support for micro-generation

In the SD scenario, feed-in tariffs (FITs) are assumed to be in place in the UK by 2011, with their assumed levels and depreciation rates being based upon current values used in Germany, converted from Euros into pounds at an exchange rate of 1€ = £0.7 (Exchange Rates 2008).

| Electricity source | Base rate / £/kWh | Depreciation rate | Source |
|---|---|---|---|
| Photovoltaics | 0.345 | 5% | BMU (2007) |
| Biomass CHP | 0.077 | 1.5% | BMU (2007) |

*Table 1.13 Feed-in tariff Rates*

In the remaining scenarios, the current UK approach of incentivising generation of renewable electricity with Renewables Obligations Certificates (ROCs) and Levy Exception Certificates (LECs) is assumed to continue up to 2030. The base income received is taken as £41.66 per MWh generated, based upon Peabody income in 2006. It is assumed that the price of ROCs and LECs stays constant in real terms to 2030.

Electricity generated by CHP is assumed to be sold to Peabody residents where possible, to maximise the financial benefits to Peabody. Electricity generated by PV is sold to the grid on estates without communal heating, based upon current Peabody practice on estates with PV, and sold to residents if electricity is already being sold to residents from a CHP installation.

It is assumed that for both estates with CHP and estates with CHP and PV used in combination, 50% of any electricity generated is used onsite (where being sold to residents) and the remaining 50% is exported to the grid (EST 2007a). It is assumed that only up to 80% of resident electricity demand on an estate can be supplied in this way, due to the inevitability of some mismatching between generation and demand (Wright and Firth 2007). If this level of supply is reached, any surplus electricity generated is exported to the grid.

For the SD and PD scenarios, a Renewable Heat Obligation (RHO) is assumed, as recently proposed by the UK government (BERR 2008c), which rewards generation of renewable heat (through solar thermal or biomass boilers) by paying 2p for each unit of heat generated.

Since the modelling work was carried out, the UK Government has indicated that it intends to bring in both FITs for micro-generation and a renewable heat obligation, although the funding levels associated with each incentive are yet to be decided (DECC 2008). As a result, the results in section 5.2.4 of the report, which quantify the impacts of each incentive being available for each scenario, should be seen as indicating some possible implications of this change of policy.

## 1.10. Costs of Measures

***Costs for fabric and individual servicing measures***

The costs associated with fabric measures and individual servicing measures are given in table 1.14 below. To calculate the cost for each measure, the basic cost of carrying out each measure (the "works cost") was used as a starting point, with data coming from Peabody where available and literature on housing refurbishment where not. All costs were checked for reliability with Peabody's cost consultants.

Following standard practice at Peabody, the works cost was then supplemented by allowances for Preliminaries, Fees and VAT, to generate an estimate of the total cost associated with the measure. Preliminaries and Fees apply to any new physical measures that are installed. A Preliminaries rate of 35% was applied to works costs for measures external to dwellings, and 20% for internal measures. Fees of 15% were then applied to the new subtotal, followed by VAT. A lower VAT rate of 5% was applied to insulation measures, heat pumps, solar PV and solar thermal installations (HM Revenue and Customs 2006). It is assumed that these costs do not change in real terms during the period 2006 to 2030.

| Measure | Works cost | Total cost | Source |
|---|---|---|---|
| Double-Glazing | £507 / $m^2$ | £1017 / $m^2$ | Dwyer (2007), Peabody |
| External Insulation | £105 / $m^2$ | £188 / $m^2$ | Dwyer (2007), Peabody |
| Internal Insulation | £70 / $m^2$ | £112 / $m^2$ | Dwyer (2007), Peabody |
| Floor insulation | £55 / $m^2$ | £88 / $m^2$ | Dwyer (2007), Peabody |
| Gas Boiler Installation | £3100 / unit | £5529 / unit | Renewables Advisory Board (2007), Peabody |
| Gas Boiler Replacement | £2200 / unit | £2844 / unit | Renewables Advisory Board (2007), Peabody |
| Gas Boiler Maintenance | £110 / yr | £142 / yr | Dwyer (2007), Peabody |
| Storage Heater Installation | £3100 / unit | £5529 / unit | Based on RTA (2003), Peabody |
| Storage Heater Replacement | £2200 / unit | £2844 / unit | Based on Renewables Advisory Board (2007), RTA (2003), Peabody |
| Storage Heater Maintenance | £10 / yr | £15 / yr | Assumed nominal cost |
| Gas cooker Maintenance | £35 / yr | £52 / yr | Based on Peabody experience |
| Mains Gas Connection | £850 / unit | £1516 / unit | Renewables Advisory Board (2007) |
| TRV Installation | £150 / unit | £239 / unit | Dwyer (2007), Peabody |
| Heat exchanger, metering and controls installation | £1500 / unit | £2391 / unit | Based on Peabody data |
| Extractor Fans installation | £500 / unit | £892 / unit | Dwyer (2007), Peabody |
| Decanting residents | £2800 / unit | £4162 / unit | Peabody |
| MVHR installation | £20 / $m^2$ | £36 / $m^2$ | Based on RTA (2003) |
| Thermal Bridges and Airtightness improvements | £13 / $m^2$ | £23 / $m^2$ | Energie Institut (2007) |
| Insulated Door | £1352 each | £2411 each | Dwyer (2007) |
| Triple-Glazing | £532 / $m^2$ | £1068 / $m^2$ | Based on Dwyer (2007) |
| Advanced solid wall insulation | £85 / $m^2$ | £135 / $m^2$ | Energie Institut (2007) |

*Table 1.14 Installation costs of measures*

### *Renewables and Communal Costs*

Installation costs of renewables and communal heating systems were based upon a combination of fixed costs per dwelling receiving the measure, and variable costs depending upon the size of installation. Works costs taken from Peabody or literature on refurbishment were transformed into total costs in the same way as reported above.

| Measure | Fixed cost | Variable cost | Annual maintenance cost | Source |
|---|---|---|---|---|
| Solar PV | n/a | £986 /$m^2$ | £7.1 /$m^2$ | Based on Defra (2007a), Renewables Advisory Board (2007), DTI (2005b) & Peabody experience |
| Ground Source Heat Pumps | £13548 / unit | n/a | £57 / unit | Housing Corporation (2008), Renewables Advisory Board (2007) |
| Air Source Heat Pumps | £8378 / unit | £279 per kWth | £57 / unit | Renewables Advisory Board (2007) |
| Solar Thermal | £2690 / unit | £1284 / kWth | £57 / unit | Renewables Advisory Board (2007) |
| Communal Gas Boilers | £1580 / unit | | £37 / unit | Based on Peabody experience |
| District Heating | £7690 / unit | n/a | n/a | Renewables Advisory Board (2007), Peabody experience |
| Gas CHP | £4459 / unit | £2230 / kWe | £114 / unit | Renewables Advisory Board (2007) |
| Biomass Boiler | £4459 / unit | £731 / kWth | £37 / unit | Renewables Advisory Board (2007) |
| Purchase of private wires | £277 / unit | n/a | n/a | Energy Efficiency Best Practice Programme (1999) |
| Purchase of electricity meters | £26 / unit | n/a | n/a | Energy Efficiency Best Practice Programme (1999) |
| Billing residents | £52 / unit | n/a | n/a | Peabody |

*Table 1.15 Costs of renewable and communal measures*

For communal heating systems and district heating, the fixed cost includes all pipework, heat exchangers and heat meters. Due to the assumption that heat demand is reduced prior to communal heating installations through fabric improvements, the fixed costs dominate the total installed communal heating costs, giving typical costs for CHP and biomass boilers of around £5500 per unit.

For solar PV, ground and air source heat pumps, solar thermal and biomass CHP, it was assumed that future installation costs will fall over time due to learning on the parts of the actors involved in their manufacture and installation (Hinnells 2005). Reductions in costs are assumed to increase with the total number of installations of a technology in the UK, so the values assumed for learning rates differ between scenarios with differing take-up of micro-generation (table 1.16). The figures used for each scenario were based upon the rollout of micro-generation either exceeding or failing to meet the levels projected by the Renewables Advisory Board (2007), leading to either a greater or a lower learning rate.

| | KLO & BD | SD & PD | Source |
|---|---|---|---|
| Photovoltaics | -2.5% / yr | -5.5% / yr | Based on Renewables Advisory Board (2007) |
| Solar thermal, Heat Pumps and Biomass CHP | -1% / yr | -4% / yr | Based on Renewables Advisory Board (2007) |

*Table 1.16 Learning rates for renewables*

## 1.11. Lifespans

The lifespans of measures are an important consideration for the financial assessment of refurbishment, affecting both when replacement installations are required, and NPV calculations (see section 1.14). The figures used are given in the table below.

| Measure | Assumed Lifespan / years | Source |
|---|---|---|
| Gas condensing boiler | 12 | Defra (2007a) |
| Electric storage heater | 20 | EST (2007b) |
| Communal heating systems | 15 | CIBSE (1999) |
| Solid wall insulation | 30 | Based on Dwyer (2007) |
| Glazing | 20 | Defra (2007a) |
| Heat Exchangers and Heat Meters | 30 | Based on Peabody data |
| TRVs and Fans | 15 | Dwyer (2007) |
| Loft Insulation | 30 | Dwyer (2007) |
| Floor Insulation | 30 | Based on Dwyer (2007) |
| Mechanical Ventilation with Heat Recovery | 15 | EST (2008) |
| Air tightness measures | 30 | Based on Dwyer (2007) |
| Communal heating pipework | 30 | Based on Dwyer (2007) |
| Photovoltaics | 25 | Defra (2007a) |
| Solar Thermal | 25 | Defra (2007a) |
| Ground Source Heat Pumps | 20 | Defra (2007a) |

*Table 1.17 Lifespans of measures*

## 1.12. Grant Funding

In the SD and PD scenarios, it is assumed that the funding recommended in Boardman (2007) is brought in for energy saving refurbishment in housing. Local Authorities establish Low-Carbon Zones in areas with a high prevalence of fuel poverty, so that in the period up to 2016, building fabric improvements and installations of renewables are carried out in these areas, and are funded entirely by Government. For any Peabody homes assumed to be in these areas in the Peabody Energy Model, measures as part of the Fabric approach, solar thermal installations and district heating connections (where viable) are paid for by Government. Boardman estimates that 20% of social housing is treated in this way. This figure is approximated in the SD scenario (with 21% of homes treated), and exceeded in the PD scenario which has a strong focus on insulation measures (30% of homes treated).

For homes not in Low-Carbon Zones, grant funding is assumed to be available for all micro-generation installations with the fraction of installation costs covered differing by scenario (5% for KLO and BD; 20% for PD; 30% for SD). This funding is available for installations of PV, solar thermal, ground source heat pumps, air source heat pumps and biomass boilers.

## 1.13. Net Present Value

To take into account that the costs and benefits over the timescale under consideration are typically given greater weight the earlier they occur (HM Treasury 2007), the Net Present Value (NPV) of each refurbishment approach was calculated to enable comparison between approaches. NPV is calculated by applying a discount rate to cash inflows and outflows over the assessment period, and summing the results. A positive NPV is typically viewed as a sign that an investment is beneficial and should be made, whilst a negative NPV indicates the lack of a financial case for an investment.

Each measure of NPV is defined by the following equation:

$$NPV = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t}$$

where: $t$ = years since start of investment period, $N$ = length of the investment period, $r$ = discount rate, $C_t$ = net cash flow (total income subtracted by total expenditure) in year *t.*
An example NPV calculation is illustrated in table 1.18. An initial investment of £1000 with a lifespan of 5 years, leads to a net cash flow of £200 in real terms for each of the following 5 years. Summing the cash flows gives the investment a total value of £0 over the 5 years, indicating that it generates neither a profit nor a loss. If a discount rate of 3.5% is used, to reflect the extra weight given to cash flows nearer to the present day, the discounted net cash flow for each year indicates a declining value attributed to the annual £200 cash flows. The total NPV of the investment, taking into account these discounted cash flows is then negative, -£97, indicating that the investment is not financially beneficial.

| Year | 0 | 1 | 2 | 3 | 4 | 5 | TOTAL |
|---|---|---|---|---|---|---|---|
| Net Cash Flow | -£1000 | £200 | £200 | £200 | £200 | £200 | £0 |
| Discounted Net Cash Flow | -£1000 | £193 | £187 | £180 | £174 | £168 | -£97 |

*Table 1.18 Example NPV calculation*

For investments considered as part of this research, the NPV figures given for each refurbishment approach are *relative to the Base approach* (so, by definition, the Base approach has an NPV of £0). They therefore represent the extra monetary value that is generated by a particular more-extensive approach (if it is positive), or the resulting reduction in value (if it is negative).

NPV is calculated for both Peabody and its residents considered as a whole (referred to in the report as “NPV”), and for Peabody considered alone (referred to as “Peabody NPV”). The former approach is used so as to identify the most cost-effective measures for carbon emission reduction, regardless of split incentives between resident and landlord (whereby landlord investments lead to savings for residents). A positive NPV in this case indicates a “social case” for the refurbishment approach, indicating that Peabody and its residents are better off as a whole by that approach. The latter approach is the more traditional application of NPV, used to measure whether it is in the financial interests of Peabody as a business to make a particular set of investments. A positive

NPV in this case indicates a “business case” for refurbishment. A negative NPV would indicate that further funding is required to make a refurbishment approach financially viable for Peabody.

For the NPV calculations in this research, N = 19, as investments are assessed for the period 2011 to 2030. The discount rate used in the KLO and SD scenarios is 3.5%, which is in line with current Peabody practice, and UK Government Treasury recommendations (HM Treasury 2007). For the PD and BD scenarios, assumed lower levels of economic growth lead to lower assumed discount rates (2% and 1.5% respectively).

The cash flows for residents and Peabody considered in the NPV analyses are illustrated in figure 1.5. The Shadow Price of Carbon is not used for the original NPV calculations, but its impact is assessed in chapter five. For the NPV calculations for Peabody and residents considered as a whole, all other cash flows illustrated are used, except for cash flows within the dotted lines, representing transfers of money between Peabody and Residents. For NPV for Peabody alone, all cash flows except the Shadow Price of Carbon and resident fuel costs are considered.

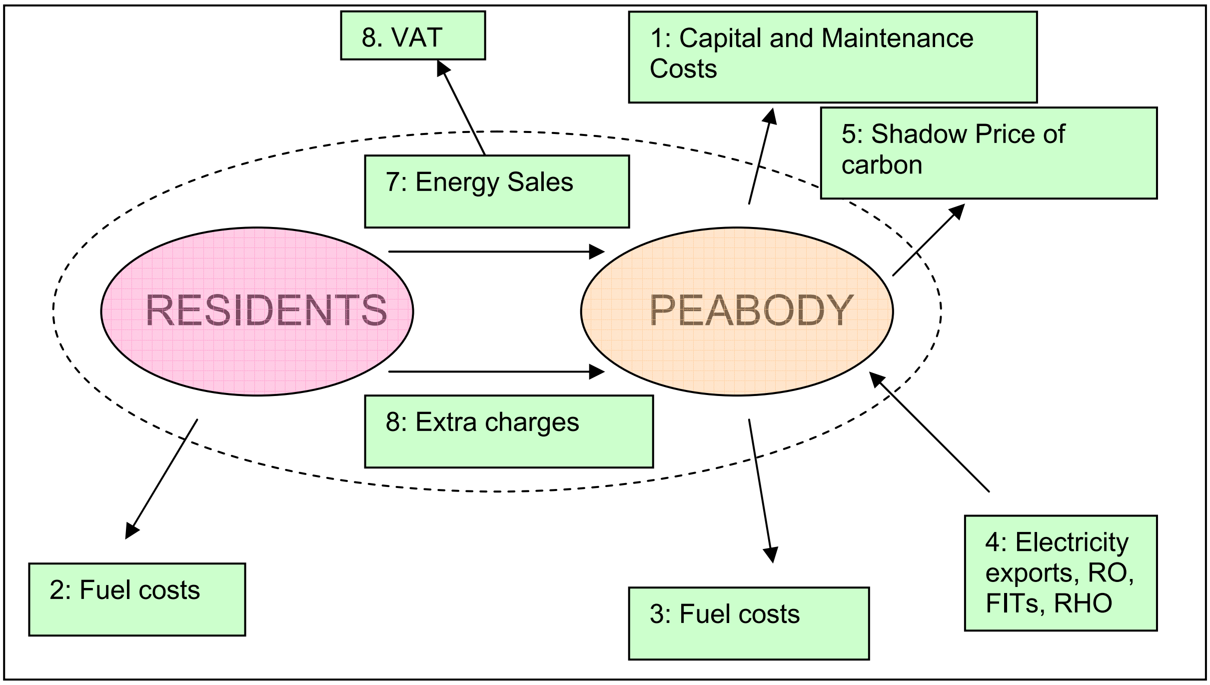


*Figure 1.5 Cashflows for Residents and Peabody considered for NPV analysis*

***Terminal Values***

The NPV calculations carried out for the Peabody model are atypical, as many investments are modelled which require significant capital expenditure, but are only installed for a fraction of their lifetime before the end of the 2011–2030 assessment period. If only expenditure and income during the assessment period was considered, this would tend to generate a bias against strategies involving capital-intensive measures such as photovoltaic panels, which would continue accruing savings beyond the 2030 horizon.

To overcome this effect, a terminal value is calculated for all measures, representing the fraction of the initial capital cost that remains “unused” by 2030, which is then considered as an income in 2030 for the NPV equation. For a measure with cost C and lifespan L, that has a lifespan beyond 2030, its terminal value is given by the equation

$$TV = C \times (\text{Lifespan remaining beyond 2030} / L)$$

where lifespans are measured in years.

### *Shadow Price of Carbon*

The financial assessment of stock refurbishment outlined above does not take into account the benefits to society as a whole of reducing carbon emissions. This issue can be addressed by putting a financial value on each tonne of carbon dioxide saved, and in this research the impact of this was assessed through Defra's shadow price of carbon (SPC). The SPC is a measure of the marginal damage caused by the emission of an extra tonne of carbon dioxide, and it is recommended by the UK Government that it is used for any public sector financial appraisal. Defra give a 2007 value for the SPC of £25, and recommend that it is increased by 2% a year in real terms beyond that date (Defra 2007d).

The SPC is not used in the base calculations for NPV and Peabody NPV, but the effects of its consideration are considered in chapter five of the report. Where the SPC is employed, the difference in annual total emissions for each year from 2011 to 2030 for each considered refurbishment approach relative to the Base approach is calculated. These figures are then converted into a monetary value using the values for the SPC provided by Defra.

## 1.14. Costs for Residents

Resident costs are calculated for each estate for each year from 2006 to 2030, using figures for energy use and the fuel cost assumptions outlined above.

### *Measuring Fuel Poverty*

A household is defined by the UK government as being in Fuel Poverty if it needs to spend 10% of its total income on fuel to provide an adequate level of energy service (Defra 2004). This approach to defining fuel poverty is disputed by several organisations, such as the fuel poverty charity National Energy Action (NEA), which support an alternative definition using a threshold of 10% of disposable income (NEA 2008).

To quantify the prevalence of fuel poverty amongst Peabody residents on each estate during the assessment period, an equation was used which estimated the percentage of households in fuel poverty based upon the average fuel costs per adult householder (i.e. householders with an income).

Based upon Peabody resident data, the number of adults per household, A, was estimated based upon the number of residents, N, using the equation

$$A = 1 + (N-1) \times 0.35$$

It was assumed that adults in Peabody homes have an income ranging between the minimum and maximum figures given in table 1.19 (based upon Peabody resident data), with the distribution skewed towards the minimum level. If average fuel costs were calculated as being below 10% of the minimum income level, no households were assumed to be in fuel poverty. Conversely if average fuel costs exceeded 10% of the maximum income, all households were assumed to be in fuel poverty. For average fuel costs between these levels, the statistical package SPSS was used to generate a function to join these start and end points, based upon an inverse relationship between fuel costs and households in fuel poverty, to take into account the high number of households on low incomes.

| Fuel Poverty Approach | Minimum Income | Maximum Income | Min. fuel poverty threshold | Max. fuel poverty threshold |
|---|---|---|---|---|
| Total Income | £7069 | £20800 | £707 | £2080 |
| Disposable Income | £2436 | £16167 | £244 | £1617 |

*Table 1.19 Minimum and maximum incomes used for fuel poverty calculations*

The accuracy of the approach as described above was improved by taking into account that a given average fuel cost for an estate represents a spread of fuel costs for the households on that estate. This consideration overcomes a potential tendency of the approach as described above to underestimate fuel poverty levels. For example, where average fuel costs per adult resident are estimated as £700 (a short way below the minimum fuel poverty threshold using the Total Income definition), the method as described above would conclude that no householders are in fuel poverty. This would be inaccurate as the average figure for fuel costs would hide significant variation between households, even for very similar dwelling types.

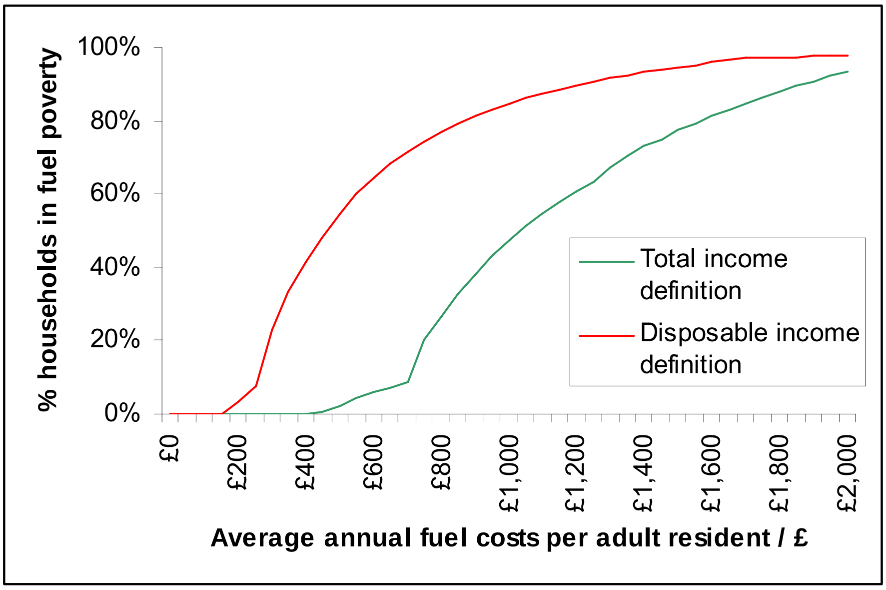


*Figure 1.6 Relationship between fuel costs per adult and fuel poverty levels*

The accuracy was improved by assuming that the spread of fuel costs making up the average made up a normal distribution. To capture this assumption simply so that it could be incorporated in the model, the assumed distribution was split into five parts using the 3-sigma rule (which states that 99.7% of a normal distribution lies within three standard deviations of the mean, with standard deviation signified as "σ" (sigma)). A standard deviation of one third of the mean was assumed so that the range of the approximated distribution goes from zero to twice the mean in each case. This gives a range of energy use that is representative of that found to date in existing research.

Five points are then considered for average fuel prices instead of one average fuel price, with their values and weights relative to the average fuel price C given in table 1.20, and their position on the normal curve illustrated in figure 1.7 (the weights represent the shaded areas as a fraction of the area under the curve). The rule described above for estimating fuel poverty based upon average fuel costs was then applied for each estate from 2006 to 2030 to each of the five values derived from the average value C to provide an improved estimate of fuel poverty that takes some account of the spread of expenditure on fuel around the average.

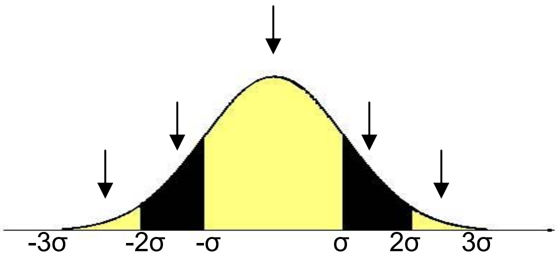


*Figure 1.7 Illustration of approximation of normal distribution*

| Weight | Value for fuel costs |
|---|---|
| 0.68 | C |
| 0.14 | C*1.45 |
| 0.14 | C*0.55 |
| 0.02 | C*1.75 |
| 0.02 | C*0.25 |

*Table 1.20 Five values used to approximate range of fuel costs*

## 1.15. Scenario Assumptions

The impact of scenarios on model assumptions is shown in the table below.

| Assumption | Keeping the Lights On | Sustainable Development | Power Down | Breakdown |
|---|---|---|---|---|
| Annual change in electricity Carbon Intensity (2011 to 2030) | -0.0099 $kgCO_2/kWh$ | -0.0174 $kgCO_2/kWh$ | As for SD | As for KLO |
| Annual change in percentage of energy used by energy efficient lighting relative to incandescent lighting (2015 to 2030) | -0.266% | -1.3% | As for SD | As for KLO |
| Annual percentage changes in energy demand (lighting; electricity; heat; hot water; cooking), 2011 to 2016; 2017 to 2030 | Lighting: no change<br>Electricity: increases annually by 1.65% to 2030<br>Heat: no change<br>Hot water: no change<br>Cooking: no change | Lighting: -2% per annum to 2016 then no change<br>Electricity: no change to 2016 then -1%<br>Heat: -2% to 2016, then no change to 2030<br>Hot water: -2% to 2016, then no change<br>Cooking: -2% to 2016, then no change | Lighting: -2% to 2016 then -1%<br>Electricity: no change to 2016 then -2% to 2030<br>Heat: -2% to 2016, then -1% to 2030<br>Hot water: -2% to 2016, then -1% to 2030<br>Cooking: -2% to 2016, then -1% to 2030 | Lighting: No change to 2016 then -1% to 2030<br>Electricity: 1.65% to 2016 then -1% to 2030<br>Heat: no change to 2016, then -1% to 2030<br>Hot Water: no change to 2016, then -1% to 2030<br>Cooking: No change, then -1% to 2030 |
| Gas prices (2009 to 2030) | 1% | 1.5% | 2.5% | 3.5% |
| Electricity prices (2009 to 2030) | 1% | 2.5% | 3.5% | 3% |
| District Heating change in carbon intensity of input fuel (2006 to 2030) | 0 | -0.0046 $kgCO_2/kWh$ | As for SD | As for KLO |
| Fraction of homes in Low Carbon Zone | 0 | 21% | 30% | 0 |
| Fraction of renewables costs covered by grants | 5% | 30% | 20% | 5% |
| Fraction of insulation costs covered by grants | 5% | 20% | 30% | 10% |
| Percentage of estates with possible district heating connection | 10% | 25% | 25% | 10% |
| Discount rate | 3.5% | 3.5% | 2% (0.5% net growth | 1.5% (zero net growth) |
| Feed in tariffs? | No | Yes | No | No |
| Renewable Heat Obligation? | No | Yes | Yes | No |
| Annual reduction in costs for PV | 2.5% | 5.5% | 5.5% | 2.5% |
| Annual reduction in costs for other micro-generation (ASHPs, GSHPs & Biomass CHP) | 1% | 4% | 4% | 1% |

*Table 1.21 Assumptions by scenario*

# 2 Appendix II: Applying the London targets to existing housing.

It is assumed for this report that the reductions in emissions required for the Peabody stock relative to a 2006 baseline are equivalent to those required for existing housing in London, based upon the targets in the London Climate Change Action Plan (GLA 2007). The derivation of these targets is described below.

The London Climate Change Action Plan aims to reduce carbon emissions in London by 20% by 2016 and 60% by 2025 (excluding emissions from aviation), based on a 1990 baseline. For housing, the report states that total emissions in 2006 are 16.7 Mt of $CO_2$, and that the targets for 2016 and 2025 are 12Mt $CO_2$ and 7.5 Mt $CO_2$ respectively. As percentage reductions relative to the 2006 baseline, these targets represent reductions of 28% to 2016 and 55% to 2025. However, these totals refer to all housing in London, and as it is planned that additional housing will be constructed in the city in the period up to 2025, some of these emissions will come from new housing. As a result, the emission reductions targets for existing housing will be greater than the 28% and 55% figures given above.

Calculating the emission reduction targets for existing housing requires assumptions on the emissions from new homes constructed in London after 2006. It is assumed that, following projections in the London Plan, 30,500 additional homes are constructed in London every year to 2016 (GLA 2004). Average emissions from a new home are assumed to decline linearly from 2007 new build levels of 4.1 tonnes per annum (Stepping Forward 2007) to zero by 2016, based upon the assumption that new homes built from that date produce zero net carbon emissions (CLG 2007). Assuming that emissions from each new home do not change to 2016 (so, for example, a home built in 2007 produces 4.1 tonnes of $CO_2$ each year to 2016), the total emissions from new homes in 2016 is 625,250 tonnes of $CO_2$. As a result the total target emissions of $CO_2$ from existing homes for 2016 becomes 12Mt subtracted by 625,250, giving 11.37 Mt. This gives a target percentage reduction in emissions relative to 2006 levels by 2016 of 31.9%.

To calculate the 2025 target, it is first assumed that by that date emission reductions have been achieved in the homes built between 2007 and 2016. Total emissions from these homes in 2025 are estimated as 62.5% of emissions in 2016, in line with the planned total emissions from housing in London reducing to 62.5% of 2016 levels by 2025 (from 12Mt to 7.5Mt). This gives emissions of 390,781 tonnes in 2025 from new homes, and total target emissions for existing housing of 7.5Mt subtracted by 390,781 tonnes, giving 7.11 Mt. This gives a target percentage reduction in emissions relative to 2006 levels by 2025 of 57.4%.

Therefore, through consideration of homes built in London after 2006, target reductions for existing homes in London are increased from 28% to 2016 and 55% to 2025 to 31.9% to 2016 and 57.4% to 2025.

If house building rates do not match those assumed for the London plan, as may be the case given the downturn in construction activity at the time of writing, this would have the effect of reducing the emission reduction target for existing housing from 57.4% towards the 55% target that would apply if no new homes were constructed.

# 3 Appendix III: Breakdown of Peabody Costs

The breakdown of Peabody expenditure from 2011 to 2030 is shown below for the three scenarios not reported in the main report body: Keeping the Lights On, Power Down and Breaking Down.

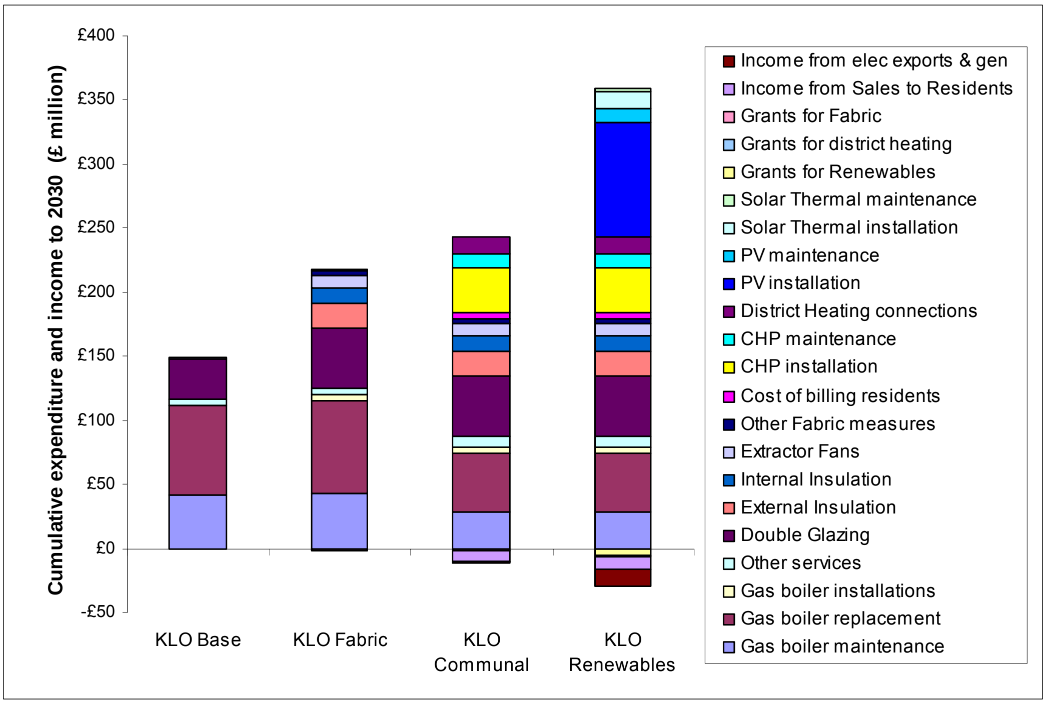


*Figure 3.1 KLO scenario: Breakdown of Peabody costs*

| | Base | Fabric | Communal | Renewables |
|---|---|---|---|---|
| **EXPENDITURE** | | | | |
| Gas boiler maintenance | £41,613,506 | £43,018,636 | £27,898,192 | £27,898,192 |
| Gas boiler replacement | £69,453,528 | £71,798,709 | £46,562,475 | £46,562,475 |
| Gas boiler installations | £0 | £4,800,767 | £4,800,767 | £4,800,767 |
| Other services | £5,646,018 | £5,236,980 | £8,305,697 | £8,305,697 |
| Double glazing | £31,113,825 | £46,986,677 | £46,986,677 | £46,986,677 |
| External insulation | £0 | £18,844,376 | £18,844,376 | £18,844,376 |
| Internal insulation | £0 | £12,875,808 | £12,875,808 | £12,875,808 |
| Extractor fans | £0 | £8,951,612 | £8,951,612 | £8,951,612 |
| Other fabric measures | £0 | £3,976,298 | £3,976,298 | £3,976,298 |
| Cost of billing residents | £0 | £587,756 | £4,898,868 | £4,898,868 |
| CHP installation | £0 | £0 | £35,522,659 | £35,522,659 |
| CHP maintenance | £0 | £0 | £10,739,826 | £10,739,826 |
| District heating connections | £0 | £0 | £12,565,460 | £12,565,460 |
| PV installation | £0 | £0 | £0 | £89,348,982 |
| PV maintenance | £212,148 | £212,148 | £212,148 | £10,467,522 |
| Solar Thermal installation | £0 | £0 | £0 | £14,307,043 |
| Solar Thermal maintenance | £0 | £0 | £0 | £2,068,644 |
| **INCOME** | | | | |
| Grants for renewables | £0 | £0 | £0 | -£5,182,801 |
| Grants for fabric improvements | £0 | -£1,586,009 | -£1,586,009 | -£1,586,009 |
| Income from sales to residents | £706,786[1] | -£105,566 | -£8,244,417 | -£9,762,259 |
| Income from electricity exports & generation | -£339,128 | -£339,128 | -£1,510,860 | -£12,618,582 |
| **Total** | **£148,406,682** | **£215,259,065** | **£231,799,578** | **£329,971,256** |

*Table 3.1 KLO Scenario: Breakdown of Peabody Costs*

1. Peabody is making a loss by selling heat to residents for this case.

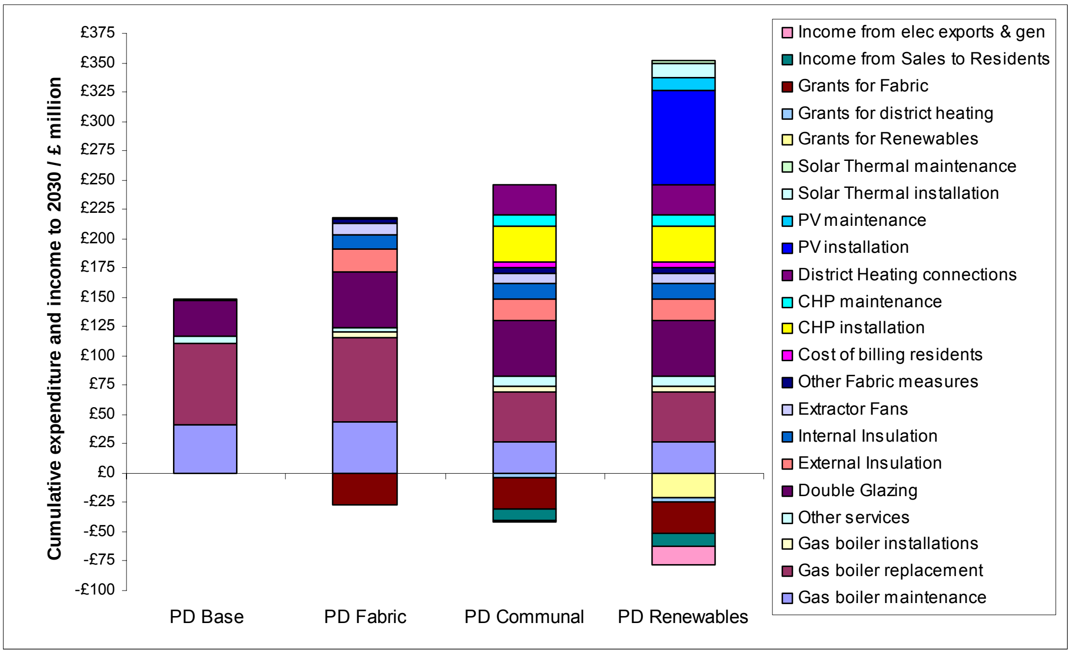


*Figure 3.2 PD Scenario: Breakdown of Peabody Costs*

| | Base | Fabric | Communal | Renewables |
|---|---|---|---|---|
| **EXPENDITURE** | | | | |
| Gas boiler maintenance | £41,613,506 | £43,123,856 | £26,128,444 | £26,128,444 |
| Gas boiler replacement | £69,453,528 | £71,974,324 | £43,608,742 | £43,608,742 |
| Gas boiler installations | £0 | £4,800,767 | £4,800,767 | £4,800,767 |
| Other services | £5,646,018 | £4,786,506 | £8,474,543 | £8,474,543 |
| Double glazing | £31,113,825 | £46,986,677 | £46,986,677 | £46,986,677 |
| External insulation | £0 | £18,844,376 | £18,844,376 | £18,844,376 |
| Internal insulation | £0 | £12,875,808 | £12,875,808 | £12,875,808 |
| Extractor fans | £0 | £9,256,320 | £9,256,320 | £9,256,320 |
| Other fabric measures | £0 | £4,311,854 | £4,311,854 | £4,311,854 |
| Cost of billing residents | £0 | £650,988 | £4,501,796 | £4,501,796 |
| CHP installation | £0 | £0 | £31,315,992 | £31,315,992 |
| CHP maintenance | £0 | £0 | £9,730,698 | £9,730,698 |
| District heating connections | £0 | £0 | £24,800,250 | £24,800,250 |
| PV installation | £0 | £0 | £0 | £80,255,859 |
| PV maintenance | £212,148 | £212,148 | £212,148 | £10,814,201 |
| Solar Thermal installation | £0 | £0 | £0 | £12,949,972 |
| Solar Thermal maintenance | £0 | £0 | £0 | £2,029,770 |
| **INCOME** | | | | |
| Grants for renewables | £0 | £0 | £0 | -£20,303,221 |
| Grants for district heating | £0 | £0 | -£4,191,050 | -£4,191,050 |
| Grants for fabric improvements | | -£26,622,423 | -£26,622,423 | -£26,622,423 |
| Income from sales to residents | £767,963[1] | -£153,595 | -£9,442,377 | -£11,454,889 |
| Income from electricity exports & generation | -£367,212 | -£367,212 | -£1,637,773 | -£14,959,955 |
| **Total** | **£148,439,776** | **£190,680,393** | **£203,954,792** | **£274,154,531** |

*Table 3.2 PD Scenario: Breakdown of Peabody Costs*

1. Peabody is making a loss by selling heat to residents for this case.

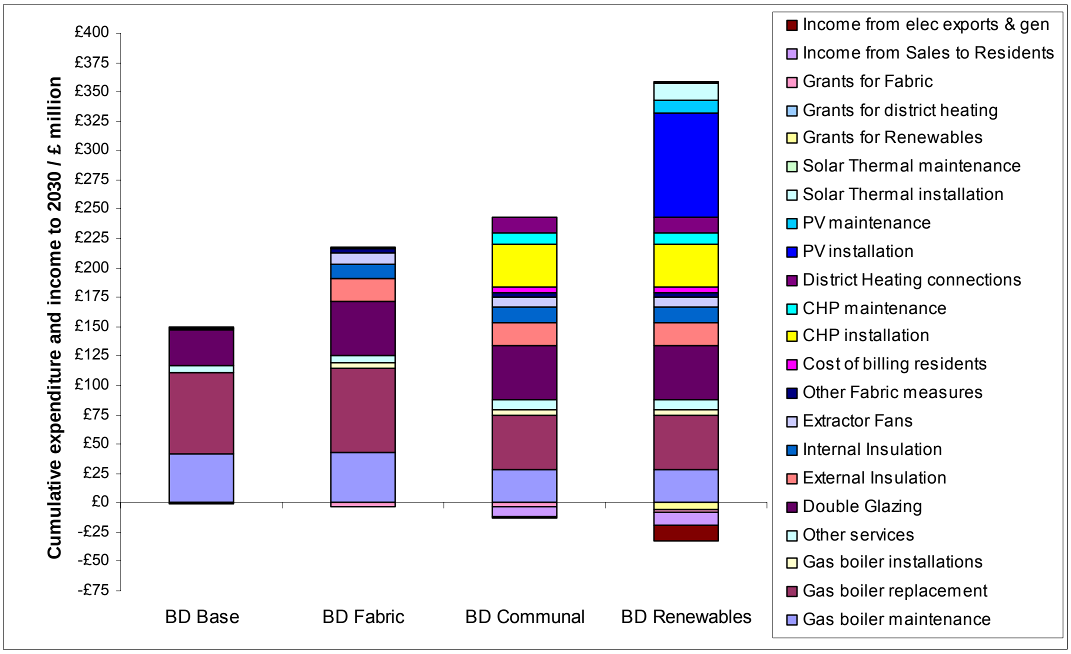


*Figure 3.3 BD Scenario: Breakdown of Peabody Costs*

| | Base | Fabric | Communal | Renewables |
|---|---|---|---|---|
| **EXPENDITURE** | | | | |
| Gas boiler maintenance | £41,613,506 | £43,018,636 | £27,898,192 | £27,898,192 |
| Gas boiler replacement | £69,453,528 | £71,798,709 | £46,562,475 | £46,562,475 |
| Gas boiler installations | £0 | £4,800,767 | £4,800,767 | £4,800,767 |
| Other services | £5,646,018 | £5,236,980 | £8,305,697 | £8,305,697 |
| Double glazing | £31,113,825 | £46,986,677 | £46,986,677 | £46,986,677 |
| External insulation | £0 | £18,844,376 | £18,844,376 | £18,844,376 |
| Internal insulation | £0 | £12,875,808 | £12,875,808 | £12,875,808 |
| Extractor fans | £0 | £8,951,612 | £8,951,612 | £8,951,612 |
| Other fabric measures | £0 | £3,976,298 | £3,976,298 | £3,976,298 |
| Cost of billing residents | £0 | £587,756 | £4,898,868 | £4,898,868 |
| CHP installation | £0 | £0 | £35,522,659 | £35,522,659 |
| CHP maintenance | £0 | £0 | 10739826 | 10739826 |
| District heating connections | £0 | £0 | £12,565,460 | £12,565,460 |
| Biomass boiler installation | £0 | £0 | £0 | £89,348,982 |
| Biomass boiler maintenance | £212,148 | £212,148 | £212,148 | £10,467,522 |
| Solar Thermal installation | £0 | £0 | £0 | £14,307,043 |
| Solar Thermal maintenance | £0 | £0 | £0 | £2,068,644 |
| **INCOME** | | | | |
| Grants for renewables | £0 | £0 | £0 | -£5,182,801 |
| Grants for district heating | £0 | £0 | £0 | £0 |
| Grants for fabric improvements | £0 | -£3,172,018 | -£3,172,018 | -£3,172,018 |
| Income from sales to residents | £1,391,296[1] | £289,486[1] | -£8,465,433 | -£10,496,185 |
| Income from electricity exports & generation | -£360,758 | -£360,758 | -£1,821,161 | -£13,732,144 |
| **Total** | **£149,069,563** | **£214,046,478** | **£229,682,252** | **£326,537,759** |

*Table 3.3 BD Scenario: Breakdown of Peabody Costs*

1. Peabody is making a loss by selling heat to residents for these two cases.

# 4 Appendix IV: Sensitivity Analysis Approach

Sensitivity analysis was undertaken to identify the potential impacts of changing variables on several outputs of the model: carbon emissions (measured as the % reduction to 2025); NPV; Peabody NPV; fuel poverty levels in 2030.

Any variables for which there was potential uncertainty over an appropriate value, or for which the appropriate value could potentially change over time were considered. For each variable considered, a maximum and minimum value were used for the analysis, either based upon judgement of the appropriate range of values for the variable where possible, or using a range of ±10% where there was a good degree of confidence about its value. This resulted in a range of uncertainty for values of between ±10% and ±50%. The latter assumption was used where uncertainty was felt to be significant, such as for the installation costs for CHP systems.

In some cases, an assumption in the model could not be increased or decreased, where it was already at a theoretical limit. In very few cases, the structure of the model made it impractical to make changes for particular variables, although in each case, these were assumptions that did not significantly affect results if changed.

The variables considered and the values used are given in the tables below.

| Factor | Variable(s) | Original Value | Low Value | High Value |
|---|---|---|---|---|
| Average floor areas | Correction factor used to calculate average floor areas | K = 0.92 | K = 0.84 | K = 1 |
| Base energy demand | Base demand for electricity, lighting, heating, hot water and energy for cooking, relative to modelled estimates | Electricity 10% less than modelled estimate, all other uses as for equations described above | Electricity 28% less than modelled estimate, all other uses 20% less than modelled estimate | Electricity 8% above modelled estimate, all other uses 20% above modelled estimate |
| Base fuel costs | Base standing charges and unit costs for gas and electricity for residents and Peabody | Various values, as given in appendix I above. | All costs reduced by 20% | All costs increased by 20% |
| Base Peabody fuel costs | 2006 costs of gas and electricity for Peabody | Gas 2.3p per unit; electricity 8.6p per unit | Gas 1.9p per unit; electricity 6.9p per unit | Gas 2.8p per unit; electricity 10.4p per unit |
| Change in ROC price | Change in income received through ROCs for renewably generated electricity | No change from 2011 | Annual 1% decrease from 2011 | Annual 1% increase from 2011 |
| CHP elec. efficiency | CHP electrical efficiency | 28% | 21% | 35% |
| CHP heat efficiency | CHP heat efficiency | 50% | 43% | 57% |
| CHP running hours | Running hours for CHP systems providing base hot water load | 6200 hours per year | 5000 hours per year | 6800 hours per year |
| Communal boiler efficiency | Communal boiler efficiency | 85% | 80% | 90% |
| Cost of administering CHP/communal heating | Annual cost of billing residents; costs per dwelling of buying electricity meters and internal wiring | £52 billing cost per dwelling; £277 per dwelling to buy internal wiring; £26 per dwelling to buy electricity meters | £41 billing cost per dwelling; £138 per dwelling to buy internal wiring; £13 per dwelling to buy electricity meters | £62 billing cost per dwelling; £415 per dwelling to buy internal wiring; £39 per dwelling to buy electricity meters |

| | | | | |
|---|---|---|---|---|
| Cost of CHP | Installation and annual maintenance costs for CHP | £4459 fixed cost per dwelling; £2229 variable cost per kWe installed; £114 per dwelling annual maintenance costs | £2229 fixed cost per dwelling; £1115 variable cost per kWe installed; £57 per dwelling annual maintenance costs | £6689 fixed cost per dwelling; £3345 variable cost per kWe installed; £171 per dwelling annual maintenance costs |
| Cost of district heating | Cost of district heating | £7690 per dwelling | £5183 per dwelling | £10198 per dwelling |
| Cost of double glazing | Cost of double glazing | £1017 per $m^2$ installed | £814 per $m^2$ installed | £1220 per $m^2$ installed |
| Cost of fabric measures | Costs of gas boiler installations, gas connections, TRVs, heat meters and extractor fans | Boiler installations: £5529; Gas connections: £1516; TRVs: £239; Heat meters: £2391; Extractor fans: £892 | Boiler installations: £4423; Gas connections: £758; TRVs: £120; Heat meters: £1674; Extractor fans: £713 | Boiler installations: £6635; Gas connections: £2274; TRVs: £359; Heat meters: £3108; Extractor fans: £1070 |
| Cost of gas boilers | Annual maintenance and replacement costs for individual gas boilers | £142 per dwelling annual maintenance, £2844 for replacement | £114 per dwelling annual maintenance, £2275 for replacement | £170 per dwelling annual maintenance, £3412 for replacement |
| Cost of insulation | Cost of external, internal and floor insulation | £188 per $m^2$ external; £112 per $m^2$ internal; £88 per $m^2$ floor | £94 per $m^2$ external; £56 per $m^2$ internal; £44 per $m^2$ floor | £282 per $m^2$ external; £167 per $m^2$ internal; £131 per $m^2$ floor |
| Cost of maintaining non-gas CH services | Cost of maintenance & replacement for gas cookers, electric heating and existing communal heating | Electric heating: £2844 replacement cost, £15 per annum maintenance; Existing communal heating: £1580 per unit replacement cost, £37 per unit annual maintenance; Gas cookers: £52 per dwelling annual maintenance costs | Electric heating: £1991 replacement cost, £8 per annum maintenance; Existing communal heating: £1264 per unit replacement cost, £30 per unit annual maintenance; Gas cookers: £26 per dwelling annual maintenance costs | Electric heating: £3697 replacement cost, £22 per annum maintenance; Existing communal heating: £1896 per unit replacement cost, £44 per unit annual maintenance; Gas cookers: £78 per dwelling annual maintenance costs |
| Displaced grid carbon intensity | Carbon emission savings by CHP/PV electricity generation (that displace grid electricity) | As defined in appendix I above | From 2006, declines linearly from 0.568 $kgCO_2/kWh$ on trajectory to reach 0 when grid carbon intensity reaches 0. | Remains at 0.568 $kgCO_2/kWh$ from 2006 to 2030 |
| District heating emissions | District Heating emissions from gas use per kWh heat generated ($kgCO_2/kWh$) | 0.33 | 0.297 | 0.363 |
| Effectiveness of insulation | Effectiveness of insulation measures in achieving expected heat demand reduction | Achieves 85% of modelled demand reduction | Achieves 70% of modelled demand reduction | Achieves 100% of modelled demand reduction |
| Estates suitable for communal heating | Percentage of estates suitable for communal heating | 80% | 60% | 100% |
| Estimated heat demand | Figures for annual heat demand per square metre for each dwelling type | Various values from Firth (2008) | All values reduced by 20% | All values increased by 20% |
| Exports of generated electricity | Percentage of electricity exported where electricity from CHP, or CHP and PV is sold to residents | 50% for both CHP alone and CHP installed alongside PV | 30% for both CHP alone and CHP installed alongside PV | 70% for both CHP alone and CHP installed alongside PV |
| External wall area | Assumed average external wall areas | As per equations described above | 20% less than original assumption | 20% more than original assumption |

| | | | | |
|---|---|---|---|---|
| FIT rate | Feed-in tariff level for PV, and PV lifespan used for FIT calculation | 34.5p per unit generated in 2011, assumed lifespan of 10 years | 25p per unit generated in 2011, assumed lifespan of 10 years | 45p per unit generated in 2011, assumed lifespan of 25 years |
| Gas boiler efficiency | Efficiency of new individual gas boilers | 90% | 86% | 94% |
| Home needing TRVs/Fans | Fraction of homes needing TRVs and extractor fans after Decent Homes | 80% needing fans; 75% needing TRVs | 65% needing fans; 60% needing TRVs | 95% needing fans; 90% needing TRVs |
| Lifespan of communal systems | Lifespans of non-gas boiler heating systems | 15 years | 12 years | 18 years |
| Lifespan of fabric measures | Lifespans of insulation, glazing, heat meters and communal infrastructure | 30 years for solid wall insulation, floor insulation, communal infrastructure and heat meters; 20 years for glazing | 20 years for solid wall insulation, floor insulation, communal infrastructure and heat meters;; 20 years for glazing | 40 years for solid wall insulation, floor insulation, heat meters and communal infrastructure; 24 years for glazing |
| Lifespan of gas boilers | Lifespan of gas boilers | 12 years | 9 years | 15 years |
| Lifespan of solar systems | Lifespans of solar PV and solar thermal | 25 years | 20 years | 30 years |
| Lifespan of storage heaters | Lifespan of storage heaters | 20 years | 16 years | 24 years |
| Max. use of onsite-generated electricity | Maximum proportion of onsite generated electricity that can be used onsite | 80% of electricity generated | 60% of electricity generated | 90% of electricity generated |
| Original boiler efficiencies | Efficiency of original boilers for heat and hot water | Various values from SAP 2005 | All values reduced by 10% | All values increased by 5% |
| Price for elec. exports | Price received in 2006 for exporting electricity to the grid | 1.7p per unit exported | 1p per unit exported | 6p per unit exported |
| Pumps, fans and HW losses | Energy used by pumps and fans, and scale of losses from hot water systems | As assumed in appendix I above. | 30% less energy used/lost than assumed orginally | 30% more energy used/lost than assumed orginally |
| PV costs | PV Costs for installation and maintenance | £986 per kWe installation costs; £7.1 per $m^2$ annual maintenance costs | £690 per kWe installation costs; £5 per $m^2$ annual maintenance costs | £1282 per kWe installation costs; £9.2 per $m^2$ annual maintenance costs |
| PV output | PV annual output per $m^2$ (kWh) | 90 (flat roof); 88 (south-facing); 75 (east/west-facing) | 81 (flat roof); 79.2 (south-facing); 67.5 (east/west-facing) | 99 (flat roof); 96.88 (south-facing); 82.5 (east/west-facing) |
| RHO rate | Renewable heat obligation rate | 2p per unit of renewable heat generated | 1p per unit of renewable heat generated | 3p per unit of renewable heat generated |
| Roof space for solar panels | Fraction of roof space suitable for solar panels | 50% for flat roofs, 75% for pitched | 25% for flat roofs, 40% for pitched | 65% for flat roofs, 80% for pitched |
| Size of terminal values | Size of terminal values assumed for NPV calculations | As defined in appendix I above | 20% less than original assumption | 20% more than original assumption |
| Solar thermal costs | Solar thermal installation and maintenance costs | £2690 per dwelling fixed costs; £1284 per kWth variable costs; £57 annual maintenance costs | £1883 per dwelling fixed costs; £899 per kWth variable costs; £40 annual maintenance costs | £3497 per dwelling fixed costs; £1669 per kWth variable costs; £74 annual maintenance costs |
| Solar Thermal Output | Solar Thermal annual output per $m^2$ (kWh) | 400 | 340 | 460 |
| Turnover of residents | Annual Turnover of Residents | 4% | 2% | 6% |
| Use of energy saving lighting | Use of energy saving lighting (fixed) | 55% originally, 5% annual increase to 2015 | 37% originally, 7% annual increase to 2015 | 73% originally, 3% annual increase to 2015 |
| | Use of energy saving lighting (non-fixed) | 0% originally, 11% annual increase to 2015 | 0% originally, 4.2% annual increase to 2030 | As for original value |

| | | | | |
|---|---|---|---|---|
| Use of pumps for communal heating | Energy used for pumping hot water | 4% of communal heat output | 2% of communal heat output | 6% of communal heat output |
| Window area on external walls | Assumed average window areas | As per equations described above | 20% less than original assumption | 20% more than original assumption |

*Table 4.1 All scenarios: sensitivity analysis assumptions*

| Factor | Variable | Original Value | Low Value | High Value |
|---|---|---|---|---|
| Discount rate | Discount rate | 3.5% | 1.5% | 5.5% |
| District heating availability | Fraction of estates with possible district heating connections | 10% | 5% | 15% |
| Elec. carbon intensity | Carbon Intensity of electricity ($kgCO_2$/kWh) | Annual reduction of 0.0099 from 2011 to 2030 | Annual reduction of 0.00175 from 2011 to 2030 | No change from 2011 |
| Energy demand change | Resident demand for heat, hot water, lighting and energy for cooking | No change | Annual reduction of 1% from 2011 to 2030 | Annual increase of 1% from 2011 to 2030 |
| | Resident electricity demand | 1.65% annual increase to 2030 | 0.65% annual increase to 2030 | 2.65% annual increase to 2030 |
| Energy saved by EE lighting | Change in fraction of lighting energy use saved by energy-efficient lighting | 0.27% annual increase in energy saving from 2015 | No change from 2015 | 1.3% annual increase in energy saving from 2015 |
| Grant funding for insulation | Fraction of insulation cost covered by grants | 5% | 0% | 20% |
| Grant funding for renewables | Fraction of renewables cost covered by grants | 5% | 0% | 20% |
| Grid elec. price change | Annual change in electricity prices from 2009 | Annual increase of 1% | Annual decrease of 1% | Annual increase of 3% |
| Grid gas price change | Annual change in gas prices from 2009 | Annual increase of 1% | Annual decrease of 1% | Annual increase of 3% |
| Learning rate for renewables | Change in costs for PV | Annual decrease of 2.5% from 2011 | Annual decrease of 5% from 2011 | No change |
| | Change in costs for solar thermal and heat pumps | Annual decrease of 1% from 2011 | Annual decrease of 2% from 2011 | No change |
| No. estates in low carbon zones | Percentage of estates in low carbon zones | 0% | 0% | 10% |

*Table 4.2 KLO scenario: sensitivity analysis*

| Factor | Variable | Original Value | Low Value | High Value |
|---|---|---|---|---|
| Discount rate | Discount rate | 3.5% | 1.5% | 5.5% |
| District heating availability | Fraction of estates with possible district heating connections | 25% | 10% | 40% |
| Elec. carbon intensity | Carbon Intensity of electricity / $kgCO_2$/ kWh | Annual reduction of 0.00175 from 2011 to 2030 | Annual reduction of 0.0269 from 2011 to 2030 | Annual reduction of 0.0099 from 2011 to 2030 |
| Energy demand change | Resident demand for heat, hot water, lighting and energy for cooking | Annual reduction of 2% from 2011 to 2016, then no change | Annual reduction of 3% from 2011 to 2016, then of 1% until 2030 | Annual reduction of 1% from 2011 to 2016, then annual 1% increase until 2030 |
| | Resident electricity demand | No change to 2016, then annual 1% reduction to 2030 | Annual 1% reduction to 2016, then annual 2% reduction to 2030 | Annual 1% increase to 2016, then no change to 2030 |
| Energy saved by EE lighting | Change in fraction of lighting energy use saved by energy-efficient lighting | 1.3% annual increase in energy saving from 2015 | 0.27% annual increase in energy saving from 2015 | As for original |
| Grant funding for insulation | Fraction of insulation cost covered by grants | 20% | 5% | 35% |
| Grant funding for renewables | Fraction of renewables cost covered by grants | 30% | 10% | 50% |

| | | | | |
|---|---|---|---|---|
| Grid elec. price change | Annual change in electricity prices from 2009 | Annual increase of 2.5% | Annual increase of 0.5% | Annual increase of 4.5% |
| Grid gas price change | Annual change in gas prices from 2009 | Annual increase of 1.5% | Annual decrease of 0.5% | Annual increase of 3.5% |
| Learning rate for renewables | Change in costs for PV | Annual decrease of 5.5% from 2011 | Annual decrease of 8% from 2011 | Annual decrease of 3% from 2011 |
| | Change in costs for solar thermal and heat pumps | Annual decrease of 4% from 2011 | Annual decrease of 6% from 2011 | Annual decrease of 2% from 2011 |
| No. estates in low carbon zones | Percentage of estates in low carbon zones | 21% | 10% | 30% |

*Table 4.3 SD scenario: sensitivity analysis assumptions*

| Factor | Variable | Original Value | Low Value | High Value |
|---|---|---|---|---|
| Discount rate | Discount rate | 2% | 0% | 4% |
| District heating availability | Fraction of estates with possible district heating connections | 25% | 10% | 40% |
| Elec. carbon intensity | Carbon Intensity of electricity / $kgCO_2$/ kWh | Annual reduction of 0.00175 from 2011 to 2030 | Annual reduction of 0.0269 from 2011 to 2030 | Annual reduction of 0.0099 from 2011 to 2030 |
| Energy demand change | Resident demand for heat, hot water, lighting and energy for cooking | Annual reduction of 2% from 2011 to 2016, then annual 1% reduction to 2030 | Annual reduction of 3% from 2011 to 2016, then of 2% until 2030 | Annual reduction of 1% from 2011 to 2016, then no change until 2030 |
| | Resident electricity demand | No change to 2016, then annual 2% reduction to 2030 | Annual 1% reduction to 2016, then annual 3% reduction to 2030 | Annual 1% increase to 2016, then annual 1% reduction to 2030 |
| Energy saved by EE lighting | Change in fraction of lighting energy use saved by energy-efficient lighting | 1.3% annual increase in energy saving from 2015 | 0.27% annual increase in energy saving from 2015 | As for original |
| Grant funding for insulation | Fraction of insulation cost covered by grants | 30% | 10% | 50% |
| Grant funding for renewables | Fraction of renewables cost covered by grants | 20% | 5% | 35% |
| Grid elec. price change | Annual change in electricity prices from 2009 | Annual increase of 3.5% | Annual increase of 1.5% | Annual increase of 5.5% |
| Grid gas price change | Annual change in gas prices from 2009 | Annual increase of 2.5% | Annual increase of 0.5% | Annual increase of 4.5% |
| Learning rate for renewables | Change in costs for PV | Annual decrease of 5.5% from 2011 | Annual decrease of 8% from 2011 | Annual decrease of 3% from 2011 |
| | Change in costs for solar thermal and heat pumps | Annual decrease of 4% from 2011 | Annual decrease of 6% from 2011 | Annual decrease of 2% from 2011 |
| No. estates in low carbon zones | Percentage of estates in low carbon zones | 30% | 21% | 40% |

*Table 4.4 PD scenario: sensitivity analysis assumptions*

| Factor | Variable | Original Value | Low Value | High Value |
|---|---|---|---|---|
| Discount rate | Discount rate | 1.5% | -0.5% | 3.5% |
| District heating availability | Fraction of estates with possible district heating connections | 10% | 5% | 15% |
| Elec. carbon intensity | Carbon Intensity of electricity / $kgCO_2$/ kWh | Annual reduction of 0.0099 from 2011 to 2030 | Annual reduction of 0.00175 from 2011 to 2030 | No change from 2011 |
| Energy demand change | Resident demand for heat, hot water, lighting and energy for cooking | No change from 2011 to 2016, then annual 1% reduction to 2030 | Annual 2% reduction from 2011 to 2016, then annual 1% reduction to 2030 | Annual 1% increase from 2011 to 2016, no change to 2030 |
| | Resident electricity demand | 1.65% annual increase from 2011 to 2016, | 0.65% annual increase from 2011 | 2.65% annual increase from 2011 to 2016, |

| | | | | |
|---|---|---|---|---|
| | | then annual 1% reduction to 2030 | to 2016, then annual 2% reduction to 2030 | then no change to 2030 |
| Energy saved by EE lighting | Change in fraction of lighting energy use saved by energy-efficient lighting | 0.27% annual increase in energy saving from 2015 | No change from 2015 | 1.3% annual increase in energy saving from 2015 |
| Grant funding for insulation | Fraction of insulation cost covered by grants | 10% | 0% | 20% |
| Grant funding for renewables | Fraction of renewables cost covered by grants | 5% | 0% | 10% |
| Grid elec. price change | Change in electricity prices from 2009 | Annual increase of 3% | Annual increase of 1% | Annual increase of 5% |
| Grid gas price change | Change in gas prices from 2009 | Annual increase of 3.5% | Annual increase of 1.5% | Annual increase of 5.5% |
| Learning rate for renewables | Change in costs for PV | Annual decrease of 2.5% | Annual decrease of 5% | No change |
| | Change in costs for solar thermal and heat pumps | Annual decrease of 1% | Annual decrease of 2% | No change |
| No. estates in low carbon zones | Percentage of estates in low carbon zones | 0% | 0% | 10% |

*Table 4.5 BD scenario: sensitivity analysis assumptions*

The following table gives sensitivity analysis assumptions used for data that do not affect the original results, but which do affect the results from chapter five of the report, where different refurbishment approaches are considered.

| Factor | Variable(s) | Original Value | Low Value | High Value |
|---|---|---|---|---|
| Assumed Shadow Price of Carbon | Assumed Shadow Price of Carbon | £27.06 per tonne of $CO_2$ in 2011 | £22.55 per tonne of $CO_2$ in 2011 | £76.67 per tonne of $CO_2$ in 2011 |
| Cost of advanced fabric measures | Cost of advanced fabric measures | Various, as given in appendix I above. | All costs decreased by 30% | All costs increased by 30% |
| Cost of biomass boilers | Installation and maintenance costs for biomass boilers, and fuel costs | Fixed installation costs: £4459 per dwelling; Variable installation costs: £731 per kWth; annual maintenance costs: £114 per dwelling; fuel costs: 2.5p per kWh in 2006 | Fixed installation costs: £3567 per dwelling; Variable installation costs: £366 per kWth; annual maintenance costs: £57 per dwelling; fuel costs: 2p per kWh in 2006 | Fixed installation costs: £5351 per dwelling; Variable installation costs: £1096 per kWth; annual maintenance costs: £171 per dwelling; fuel costs: 3p per kWh in 2006 |
| Cost of heat pumps | Installation and maintenance costs for GSHPs and ASHPs | GSHP installation cost: £13548 per dwelling; ASHP fixed installation cost: £8378 per dwelling; variable installation cost: £279 per kWth; Annual maintenance costs for both £57 per dwelling | GSHP installation cost: £9484 per dwelling; ASHP fixed installation cost: £5864 per dwelling; variable installation cost: £195 per kWth; Annual maintenance costs for both £40 per dwelling | GSHP installation cost: £17613 per dwelling; ASHP fixed installation cost: £10891 per dwelling; variable installation cost: £363 per kWth; Annual maintenance costs for both £74 per dwelling |
| Efficiency of biomass boilers | Efficiency of biomass boilers | 85% | 80% | 90% |
| Efficiency of heat pumps | Coefficient of performance for producing heat and hot water using GSHPs and ASHPs | GSHPs: 2.4 for heat, 1.68 for hot water; ASHPs: 1.88 for heat, 1.31 for hot water | All values decreased by 10% | All values increased by 10% |
| Heat demand achieved by advanced fabric measures | Heat demand achieved by advanced fabric measures (modified by effectiveness of insulation constant) | 19.5 kWh/m$^2$ for flats, 23.8 kWh/m$^2$ for houses | 15.6 kWh/m$^2$ for flats, 19.0 kWh/m$^2$ for houses | 23.4 kWh/m$^2$ for flats, 28.6 kWh/m$^2$ for houses |

*Table 4.6 Sensitivity analysis assumptions for variables that do not affect original results*

# 5 Appendix V: Method used for changing model variables to meet targets

As part of the sensitivity analysis, a number of key variables were identified which could vary significantly and, if changed, could significantly affect the model results. The variables explored in this way were: resident demand for energy; carbon intensity of grid electricity; discount rate; grant funding; fuel costs; refurbishment costs; refurbishment costs for alternatives to base approach.

For each variable, the value(s) required to give a desired result were calculated for four model outputs: $CO_2$ emission reductions to 2025; NPV; Peabody NPV; fuel poverty levels in 2030. The desired results used for each output were respectively: 57.4% emission reductions; zero NPV; zero Peabody NPV; no households in fuel poverty. This was achieved using the “Goalseek” function in Microsoft Excel, which allows the value of a variable that gives rise to a specific numeric output to be calculated. This was done for each scenario considered and each of the four approaches to refurbishment within that scenario.

For the refurbishment costs assumption, it was assumed that all costs were multiplied by some constant (with an original value of 1, which would give no change in the original assumed costs), and the value (if any) of this constant that allowed a zero NPV / Peabody NPV to be achieved was calculated.

For the refurbishment costs for alternatives assumption, the above approach was applied, but only to measures that are applied to a greater extent in alternative refurbishment approaches to the base approach. These measures were all the measures considered for the Fabric, Communal and Renewables approaches that did not form part of the Base approach, although double glazing is included (as it is done to a greater extent through the Fabric approach).

For the assumption on carbon intensity of grid electricity, it was assumed that the annual assumed change from 2011 was either increased or decreased by some constant value, and the value required to achieve a 57.4% emission reduction was calculated. The result of this was then reported as the value for grid intensity in 2025, rather than the revised annual reduction in grid intensity up to that period.

For the assumption on fuel costs, it was assumed for simplicity that the annual percentage changes in prices from 2008 are the same for gas and electricity. The values for annual percentage change in prices that led to a zero NPV and the values that led to a zero Peabody NPV were then calculated (if they existed).

For resident energy demand, it was assumed for simplicity that demand for each type of energy service (heat, hot water, etc.) changed to the same degree, so that a level of change that led to the GLA’s 2025 target being met could be identified. It was assumed that demand for each use and each year was increased or decreased annually by the same percentage, so that the value that led to exactly 57.4% reductions being achieved by 2025 could be calculated. The results are then presented as the percentage change in demand for each use by 2025.

For the discount rate assumption, calculating an alternative value that led to a zero NPV or a zero Peabody NPV was straightforward, as only one input variable for the model needed to be changed.

With regard to grant funding, an equal percentage of grant funding for capital costs for insulation and micro-generation measures is assumed. It is also assumed that this percentage of estates are refurbished at no cost to Peabody through “Low Carbon Zones” funding.

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