Communities
and Local Government

Research to Assess the Costs and Benefits of the Government's Proposals to Reduce the Carbon Footprint of New Housing Development

Contract Number RAE 3/15/9

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September 2008
Department for Communities and Local Government: London

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Online via the Communities and Local Government website: www.communities.gov.uk

September 2008

Product Code: 08 NHSD 05505

ISBN: 978-1-4098-0443-7

Contents

This report was commissioned from Cyril Sweett, Faber Maunsell and Europe Economics by the Department for Communities and Local Government, with support from Department for Environment, Food and Rural Affairs, to support the Regulatory Impact Assessment for the Building a Greener Future: Policy Statement issued in July 2007 (http://www.communities.gov.uk/publications/planningandbuilding/building-a-greener). The report was finalised in March 2008.

The findings and views expressed in this report are those of the authors and do not necessarily represent those of the funding Departments.

The figures used in this report should not be regarded as definitive. At the time of publication it is anticipated that an update of the analysis will be published in due course in support of the forthcoming consultation paper on the definition of zero carbon.

Executive Summary

Key Results

Analysis of the costs and benefits of the proposed policy options for progressively enhancing Building Regulations (by 25% in 2010, 44% in 2013 and with all new homes being zero carbon from 2016) indicates that:

- By 2020 the policy is expected to be generating carbon reductions of between 2.62Mt to 3.16Mt per annum
- By 2020 this policy could generate 1.4% of total projected UK electrical energy
- The average construction cost premium for delivering zero carbon homes entirely within the development site could be between 17% to 24% over current build costs by 2016 but would, over time, decrease from this peak as the costs of key technologies fall
- Annual fuel bill savings could be up to £387 per dwelling
- Increased net benefits are expected in larger scale development or where smaller developments can share common/district wide technologies
- Where Combined Heat and Power (CHP) (gas or biomass) systems are used to deliver carbon reductions the operational viability of the system is dependent on the percentage of energy that would need to be exported from a private wire system and the price paid of these exports
- Embodied carbon should not be a barrier to the policy as all of the technology options under consideration have short carbon paybacks

- At least up until 2016, policy implementation would be more efficient, with lower costs and greater carbon savings, if developers could be encouraged to take into account the ongoing costs and benefits of different options when determining their technical solution
- Technology constraints mean that it will be more difficult to achieve major carbon reductions in small high density (eg City Infill sites) developments. This is largely because of the lack of available roof/façade space that is suitable for placement of photovoltaic panels. These developments may require fundamental re-design to achieve zero carbon by on-site means alone
- There is potential for a significant change in dominant low carbon technology after 2016 indicating that the technologies used to implement the proposed changes to Building Regulations in 2010 and 2013 will not necessarily help to prepare the industry to deliver zero carbon
- The technologies expected to predominate after 2016 are photovoltaic (PV), biomass CHP and wind
- A major spike in demand for key technologies (eg biomass CHP and PV) is predicted after 2016 and this is likely to put a strain on the ability of the market to respond
- To help the industry adapt to the step change proposed for 2016, consideration should be given to the phasing of implementation of the policy, perhaps by progressively applying it to different types of development
- A review should be undertaken of the potential capacity of the biomass CHP market to meet future demand
- Permitting off-site renewable technologies would have a fundamental impact on the cost of delivering carbon reductions, but without some energy efficiency backstops could result in developments failing to go beyond current Building Regulations requirements

Priorities for Further Analysis

This is one of the first pieces of research to consider the implications of achieving zero carbon housing in England. Significant further work is required to address some of the key issues arising, including:

- The extent and conditions under which offsite renewable energy sources could be used to supplement/replace energy generated on-site
- The wider implications of encouraging the widespread adoption of biomass based technologies throughout the UK (eg fuel supply and pricing and impact on air quality)
- The integration of the predicted expansion of locally generated electricity within existing regulatory regimes (including export pricing and ability to change suppliers) and the Renewables Obligation as currently structured

- The role of Energy Supply Companies (ESCOs) in delivering zero carbon developments

Introduction

This report describes research commissioned by Communities and Local Government to assess the possible implications of revising the current Part L1a of the Building Regulations in 2010, 2013 and 2016. The proposed revisions will impose progressively tighter restrictions on the carbon emissions of new dwellings, culminating in a requirement for all new housing to achieve zero carbon status from 2016.

The research considers the costs (capital and ongoing) and the benefits (financial and environmental) of achieving this target through a number of alternative policy options.

Method

The research is based around the development of a dynamic cost and benefit model which selects the optimal[1] combination of measures required to achieve a specific carbon reduction against a baseline of Building Regulations Part L1a 2006.

The results of this research are based upon the analysis of five alternative policy options. The policy intervention options variously consider:

- The phased implementation of the policy at key stages in 2010, 2013 and 2016
- The permitting of contributions from offsite renewable energy schemes to offset the carbon emissions from proposed developments
- The setting of mandatory minimum levels of energy efficiency prior to the selection of renewable technologies

Each policy option was modelled twice. Firstly, while optimising on capital cost only (ie the cost of installing the required technologies within the new housing developments), and secondly on the basis of the combined effect of capital costs and the further costs and benefits expected to arise over the life time of the technologies. Therefore, a total of 10 policy interventions were considered, as shown in Table S.1. A further model, known as the ‘reference case’, estimates the performance of the projected new housing in the absence of any new policy.

The results of each intervention case are presented net of the reference case to identify the likely impact (costs and benefits) arising specifically from each policy option.

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[1] The optimisation is based either exclusively on capital cost or a combination of capital cost and operating costs and benefits.

Table S.1: Considered policy options

Policy option	Improvement on Part L1a 2006			Optimisation based on
	2010	2013	2016	
1: Base case	25%	44%	Zero carbon (all carbon saving measures on-site, no mandatory energy efficiency level)	Capital cost
1a: Base case				Capital and ongoing costs and benefits
2: As Option 1 but missing out the interim (44%) step	25%	25%	Zero carbon (all carbon saving measures on-site, no mandatory energy efficiency level)	Capital cost
2a: As Option 1a but missing out the interim (44%) step				Capital and ongoing costs and benefits
3: Allowing offsite generation after 2016 without energy efficiency backstops	25%	44%	Zero carbon (some or all of the carbon reduction can be secured from offsite sources)	Capital cost
3a: Allowing offsite generation after 2016 without energy efficiency backstops				Capital and ongoing costs and benefits
4: Allowing offsite generation after 2016 with mandatory energy efficiency backstops	25%	44%	Zero carbon (some or all of the carbon reduction can be secured from off-site sources, but it is necessary to achieve Energy Saving Trust (EST) Advanced Practice levels of energy efficiency)	Capital cost
4a: Allowing offsite generation after 2016 with mandatory energy efficiency backstops				Capital and ongoing costs and benefits
5: As base case but with mandatory energy efficiency backstops (equivalent to the requirements of level 6 in the Code for Sustainable Homes)	25%	44%	Zero carbon (it is necessary to achieve EST Advanced Practice levels of energy efficiency)	Capital cost
5a: As base case but with mandatory energy efficiency backstops (equivalent to the requirements of level 6 in the Code for Sustainable Homes)				Capital and ongoing costs and benefits

Results

The costs and benefits associated with each policy option are shown in Figure S.1 and Tables S.2 and S.3. The presented costs and benefits are net of the reference case and therefore represent the additional costs of the policy options rather than the total predicted cost (some of which would have been incurred in response to existing policy measures).

Figure S.1: Summary of the net present cost of each policy option

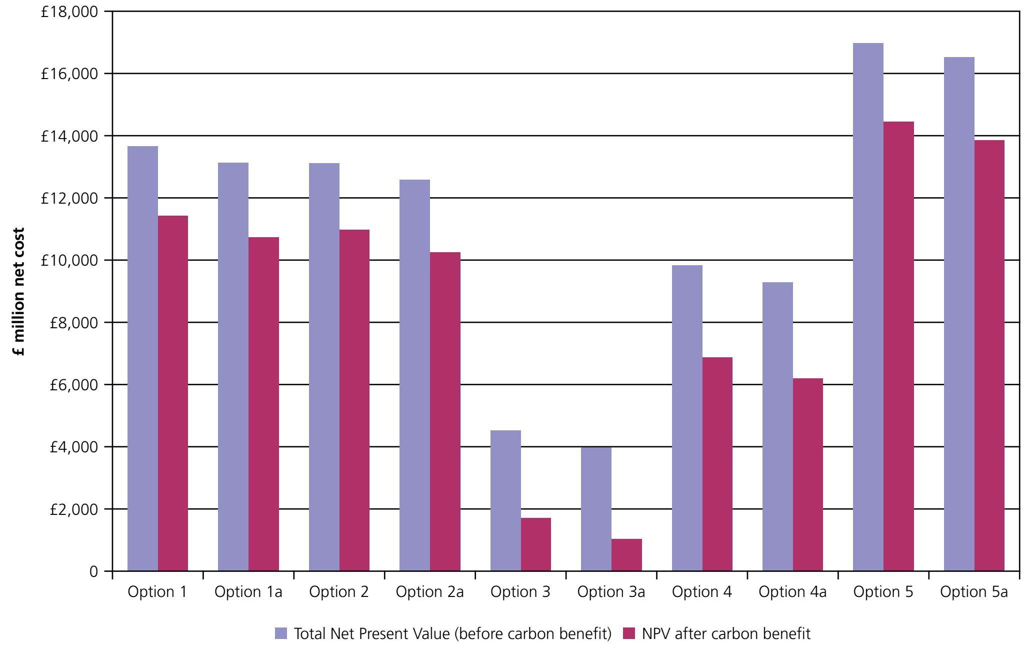


Table S.2: Summary of overall results for different policy options (medium scenario)

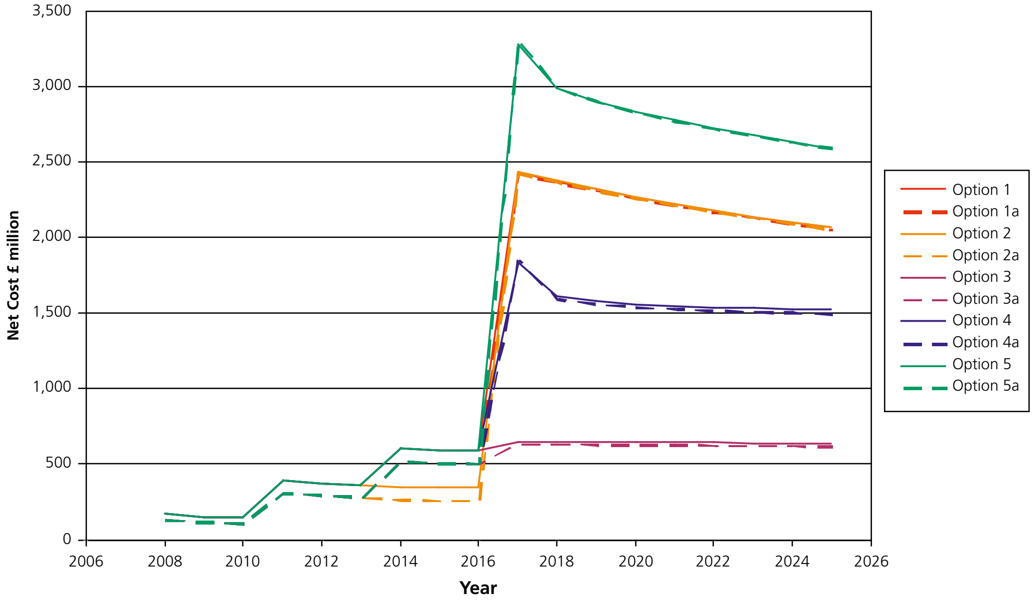
Option	Total benefits (£) PV	Total costs (£) PV	Offset payments	Total NPV (before carbon benefit)	Carbon benefit (from homes built to 2025)	NPV after carbon benefit	Abatement cost	Abatement cost	Annual CO_2 savings by 2020 (undiscounted)
	£m	£m	£m	£m	£m	£m	£ per t of CO_2 (discounted)	£ per t of CO_2 (undiscounted)	million t
Option 1	£21,889	–£35,547	£0	–£13,658	£2,239	–£11,420	£213	£108	2.85
Option 1a	£23,429	–£36,568	£0	–£13,139	£2,407	–£10,732	£191	£97	3.15
Option 2	£20,767	–£33,877	£0	–£13,110	£2,130	–£10,980	£214	£109	2.62
Option 2a	£22,581	–£35,163	£0	–£12,582	£2,332	–£10,250	£188	£96	2.98
Option 3	£4,603	–£4,985	£4,145	–£4,527	£2,819	–£1,707	£60	£27	2.86
Option 3a	£6,650	–£6,639	£3,987	–£3,977	£2,939	–£1,038	£50	£23	3.16
Option 4	£8,898	–£15,342	£3,392	–£9,836	£2,957	–£6,879	£127	£56	2.86
Option 4a	£10,680	–£16,674	£3,293	–£9,287	£3,086	–£6,201	£114	£51	3.16
Option 5	£23,912	–£40,884	£0	–£16,973	£2,521	–£14,452	£246	£115	2.82
Option 5a	£25,252	–£41,776	£0	–£16,523	£2,667	–£13,857	£226	£107	3.12

Table S.3: Increase in construction costs over 2006 Part L1a for different policy options (medium scenario)

Option	**Increase in construction costs (over Part L) in 2011**	**Increase in construction costs (over Part L) in 2014**	**Increase in construction costs (over Part L) in 2017**	**% increase in construction costs (over Part L) in 2025**
	%	%	%	%
Option 1	2.5%	5.0%	17.8%	14.3%
Option 1a	3.1%	5.8%	17.9%	14.4%
Option 2	2.5%	2.3%	17.9%	14.3%
Option 2a	3.1%	3.0%	17.9%	14.4%
Option 3	2.5%	5.0%	4.7%	4.6%
Option 3a	3.1%	5.8%	5.3%	5.1%
Option 4	2.5%	5.0%	12.7%	11.9%
Option 4a	3.1%	5.8%	13.3%	12.4%
Option 5	2.5%	5.0%	23.6%	17.7%
Option 5a	3.1%	5.8%	23.9%	17.7%

Figure S.2: shows the comparative net present cost of each Policy Option per annum projected to 2025

Figure S.2: Comparative net present cost of each Policy Option (medium scenario) to 2025



These results indicate that:

- Net costs are highest for Options 5 and 5a. These options require all of the carbon reductions to be achieved on-site and there is an obligation for at least Advanced Practice levels of energy efficiency. After 2016, these two options most closely resemble the standard required by level 6 of the Code for Sustainable Homes. Costs are higher for these options because: a) all carbon reduction must be achieved on-site; and, b) it is necessary to achieve high levels of thermal performance in each home. High thermal performance standards have the effect of both increasing costs and reducing the carbon effectiveness of CHP systems (by reducing the overall heat demand of the homes and hence the potential to produce low carbon electricity).
- After 2016 (ie once the zero carbon standard is in place), there is little or no impact on net costs between options optimised on capital cost only and those taking capital and ongoing costs into account. However, before 2016 net costs are lower where both capital and ongoing costs and benefits are taken into consideration. As a result the cumulative net costs by 2025 are lower for those options that include ongoing cost in the optimisation process than for those where only capital cost is considered.
- Policy Options 2 and 2a have slightly reduced net costs in comparison to Options 1 and 1a. This is because of the avoidance of the change in Building Regulations in 2013 (to a 44% improvement on the current position). Not surprisingly Options 2 and 2a also result in slightly lower overall carbon reductions than under Options 1 and 1a. The abatement costs (£ per tonne of carbon saved) are virtually identical for Options 1 and 2 and 1a and 2a indicating that while a tightening of regulations in 2013 reduces overall carbon emissions it does not increase the overall efficiency of the policy option by 2025.
- After 2017 (the date by which it is assumed policy changes in 2016 will have come into effect) Options 3/3a and 4/4a have substantially lower net costs than those options requiring all carbon savings to be achieved on-site. It should be noted however that Option 3/3a will have little or no impact on the quality of new housing after 2016 and that as a result no direct benefits will accrue to homeowners.

The technologies used to deliver the required performance in each year vary with each option; Figure S.3 shows the total[2] aggregate capital costs per annum for Option 1 apportioned against the dominant technology options. While basic energy efficiency measures are used throughout the modelled period, there is no demand for very high performance levels (ie EST Advanced Practice); instead

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[2] ie not net of the reference case. We have chosen not to remove the reference case from these figures in order to show the total estimated demand for each technology type.

carbon reductions are achieved largely through the use of photovoltaics (PV) and biomass heating/CHP systems. When the same policy option is modelled by optimising on capital and ongoing costs and benefits (Option 1a) the dominant technologies after 2016 are the same as for Option 1, but prior to this they also include Gas CHP, as shown in Figure S.4.

Figure S.3: Total aggregate capital costs per annum apportioned against the dominant technology options; Option 1 (medium scenario)

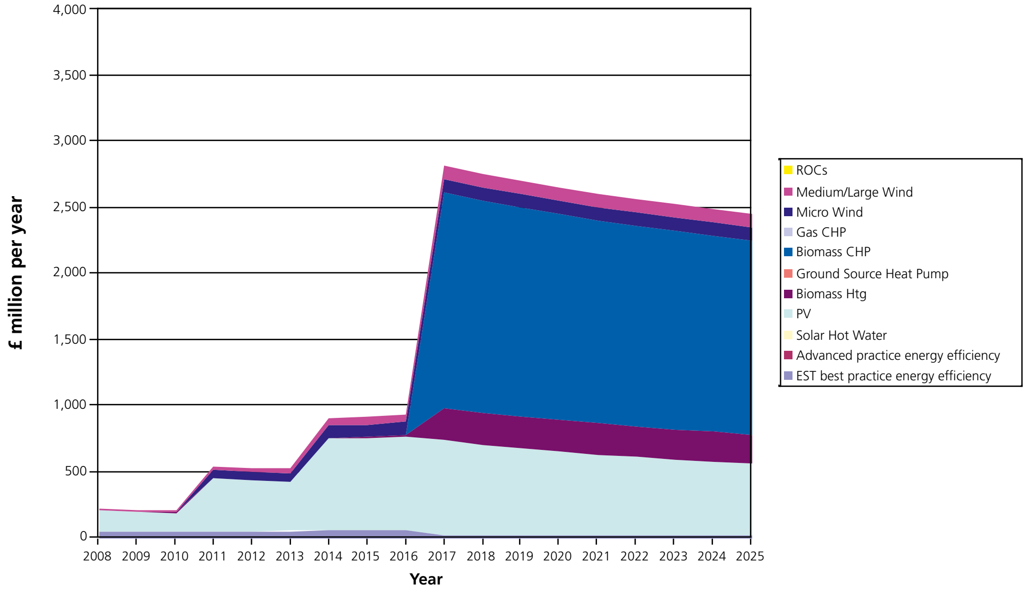
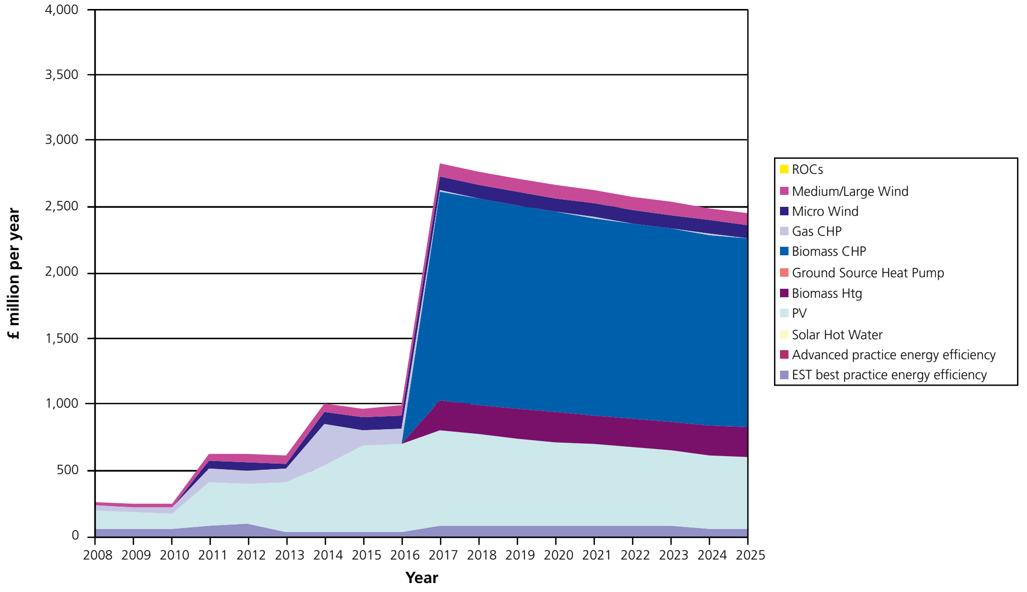


Figure S.4: Total aggregate capital costs per annum apportioned against the dominant technology options; Option 1a (medium scenario)



Findings

Environmental benefits

Whichever policy alternative is ultimately taken forward, the amount of CO_2 saved per annum by 2020 is broadly consistent, ranging between 2.62 Mt to 3.16 Mt. Further, by 2050, the dwellings built up to 2025 will save an estimated 6.2 Mt per annum or 195 Mt in total[3]. If construction rates continued at 2025 levels through to 2050 then the carbon saving achieved in comparison to current practice could be 21.5 Mt per annum in 2050 or 392 Mt in total.

Annex B of the DTI document *Meeting the Energy Challenge – A White Paper on Energy, May 2007* estimates that by 2020 UK energy generation could total 367 TWh based upon Central policy estimates. From the modelling, it is estimated that, by 2020 the total of electrical energy being generated by renewable sources as a direct consequence of the policy could total 5.2 TWh; equivalent to approximately 1.4% of the total UK electrical energy projection.

One potential limitation to achieving full zero carbon status, however, is that the results show that City Infill developments would not be able to achieve zero carbon status with the technologies and design options considered in the study. All of the other development types modelled were able achieve zero carbon using on-site technologies. Analysis of the shortfall in carbon reductions arising on the City Infill sites showed that it is also possible to achieve zero carbon status for this scenario using on-site technologies, but that this would require careful redesign to increase the area of roof/exposed surface on which PV could be placed.

Embodied carbon should not act as a barrier to encouraging zero carbon housing developments under the policy, with carbon payback on technology options being achieved within a small fraction of their overall lifespan.

Financial costs and benefits

For options relying on on-site technologies only, the construction costs of achieving zero carbon in 2016 are likely to be between 17% and 24% higher than the costs for dwellings built to the standards of Building Regulations Part L1a 2006, but this should fall in future years, as learning rates reduce the cost of low carbon technologies. By 2025 the increase in compliance costs would be between 14% and 18%.

Translating these costs into a total net present cost associated with the application of a full on-site policy to all dwellings projected to be constructed to 2025, gives an estimated range of £10.2 billion to £14.4 billion, depending upon the policy option.

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[3] Assuming that they maintain their zero carbon status in perpetuity.

Improved energy efficiency together with reduced reliance on grid supplied electricity means that annual fuel bill savings of up to £387 per annum could be achieved. However, it is likely that part (or the majority) of these savings could be taken up in the maintenance and management of the technologies involved.

Allowing part or all of the required carbon reduction after 2016 to be achieved through contributions to offsite renewable energy schemes has a significant impact on both the costs and benefits of the policy.

Where offsite contributions are allowed after 2016 the overall costs of the policy could be as low as £3.9 billion (or £1.0 billion after carbon benefit). However, the impact of allowing unrestricted levels of offsite carbon reductions after 2016 would be to reduce incentives to build to higher levels of energy efficiency. This is seen in the results, whereby, the construction standards and costs drop back to a level reflective of current standards (see Options 3 and 3a) and all carbon reduction (with the exception of large scale wind) is achieved offsite. As a result there would be fewer tangible benefits to homeowners in terms of fuel bill savings, overall operational cost reductions and, arguably, in terms of the quality of their housing.

Even with the inclusion of an energy efficiency backstop (at EST Advanced Practice), fuel bill savings do not exceed £190 per annum when offsite solutions are allowed to deliver the majority of the required carbon reduction. Nonetheless the relative impact of these options on capital costs is much lower with the percentage increase on current requirements at between 5.3% (Option 3) and 13.3% (Option 4a) in 2016.

The results based upon optimising on total costs and benefits over the life time of an asset generate lower costs overall, increased carbon savings and lower carbon abatement costs. However, as discussed previously (see Figure S.2), this is not significant post 2016. This suggests that at least in the short term measures aimed at raising awareness of the operational costs and benefits of different policy options result in more efficient policy implementation.

Technological Impact

Up to 2016, the performance improvements required by the policy options can be achieved, relatively cost effectively, through a mix of technologies including photovoltaic (PV), wind, biomass heating, solar water heating and improved energy efficiency measures. No one particular technology dominates in these years, suggesting that industry should be able to develop to meet demand in a manner which avoids problems of over demand, excessive supply periods, etc.

After 2016, the three technologies tend to predominate namely PV, biomass CHP and wind. This raises a number of key issues related to the evolution of the technology mix and the scale of demand for key technologies. The results show that even with the progressive implementation of the policy[4] it is still likely that there will be changes in the core carbon saving technology post 2016. Therefore, the solutions that deliver the standards required post 2010 and 2013 may not effectively prepare the industry to deliver zero carbon post 2016. While the incremental introduction of the policy should afford industry the opportunity to prepare for the change to zero carbon it does not provide a smooth learning curve arising from increasing application of the same technologies and as a result is not the optimal preparation for achieving the zero carbon standard.

The predominance of biomass technologies, largely heating systems pre 2016 and CHP post 2016, is significant. Biomass CHP is currently still an emerging technology and the long term viability of all biomass technologies is sensitive to the stability of the supply and price of the fuel[5] and the ability to manage any concerns related to cumulative impacts on air quality when used in high concentrations.

It should also be noted that there is likely to be an anomaly in the overall costs where biomass CHP is used in conjunction with very high mandatory levels of energy efficiency (eg the current Code for Sustainable Homes Level 6 requirement). A cost increase is seen where EST Advanced Practice energy efficiency measures are mandatory because in addition to the increased costs of these measures, the resulting reduction in heating load reduces the carbon reductions achieved from biomass CHP systems.

Where medium/large wind technology is possible this is the most cost effective carbon reduction option. However, wind also has its own locational sensitivities and the number of sites in England where the use of medium to large scale turbines is possible or desirable remains to be seen.

In this modelling micro wind technologies were only considered viable for a small number of sites and excluding its use has only a marginal effect on the results.

Potential for replacement of Low and Zero Carbon (LZC) technologies at the end of their service life

If the capital cost is written off, all of the considered low carbon options deliver operational cost savings in comparison to traditional alternatives[6], the only exception being biomass CHP in the City Infill scenario. However, an important test is whether the scale of these savings is sufficient to fund replacement of the technology at its end of life.

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[4] With changes in performance standards in 2010, 2013 and 2016.

[5] Although the same concerns about fuel price could be raised in connection with natural gas

[6] ie a gas fired condensing boiler

By estimating the present value of energy savings arising over 40 years (the duration of some energy services company (ESCO) contracts) and comparing these to the present value of maintenance and replacement costs it is possible to achieve overall savings for:

- PV
- Ground Source Heat Pumps
- Biomass heating
- Gas CHP (for Market Town and Urban Regeneration developments)
- Biomass CHP (for Urban Regeneration developments)
- Medium and large scale wind turbines

This suggests that, given a sufficiently long management period, it should be possible maintain the zero carbon status of homes once they have been built to this standard. However, it should be stressed that this assessment does not replicate the intricacies of an ESCO business model which would include a range of complex financing arrangements.

Sensitivity to energy price changes

The results presented in this study assume that energy prices do not change over the duration of the study period. To assess the impact of different energy price trends, the costs and benefits of the Base Case policy (Option 1) were modelled using two alternative price scenarios[7]. The results indicated that, although total capital costs were the same for each scenario, the comparative life time costs reduced significantly with increasing energy projections (thereby increasing the overall benefit of the policy). Conversely, the comparative life time costs increased significantly with decreasing energy projections (thereby reducing the overall benefit of the policy). The high energy price scenario indicated that in a scenario of year on year energy price increases, the overall comparative NPV of Option 1 could reduce by up to 16.5% to –£9.5 billion. However, the low energy price scenario indicated that in a scenario of year on year energy price decreases, the overall comparative NPV of Option 1 could increase by up to 29% to –£14.7 billion.

Clearly, future energy prices are highly uncertain. However, the results indicate that the net cost of the policy is highly sensitive to change in energy prices and particularly the differential costs of gas and biomass fuels.

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[7] projected price change profiles were developed using Communities and Local Government indicative data on average price of domestic fuel for the period 2006 to 2020

Pricing of energy sold into the grid

The modelling undertaken in this study assumes that all of the energy generated within a development can be used within the development or sold into the grid at a competitive price. At present relatively few utilities are prepared to purchase locally generated electricity at retail prices and it could be assumed that this would become increasingly rare as the quantity of locally generated energy increases. Therefore on sites where there is likely to be a considerable amount of energy exported from the site during the year (typically smaller sites and those without a suitable mix of uses within the private wire network) the value of the annual reductions in fuel bills could be less than those estimated here.

The inability to find a suitable market for locally generated electricity (eg from a CHP system) is a potential limitation on the uptake of these technologies even if the capital cost is discounted and consideration should be given to the most efficient ways of ensuring market access and tariffs for energy exported into the grid.

Eligibility for Renewables Obligation Certificates (ROCs)

A further consideration is whether renewable energy installed to achieve Building Regulations standards will be eligible for Renewables Obligation Certificates (ROCs). In this study it is assumed that new homes are not eligible for income from the sale of ROCs, because doing so would remove the additionality of the carbon savings achieved. Nonetheless, in practice, it could be difficult to distinguish between renewable energy generated to meet a Building Regulations requirement and that installed for other reasons (for which ROCs would be eligible). Therefore, for administrative clarity it may be necessary for all domestic renewable energy to be eligible for ROCs.

If this were the case it would be necessary to re-evaluate the operation of the Renewables Obligation to review the options for securing additionality for credits obtained by new housing and to determine responsibility for funding the additional ROCs required.

If all domestic renewable energy generation were eligible for ROCs then the benefits of renewable technologies would increase in comparison to energy efficiency measures and the business case for ESCO involvement in the supply and maintenance of renewable technologies would be strengthened.

Development Scale

As previously discussed, City Infill developments may not currently be able to reach zero carbon using only on-site solutions without new design solutions to increase the area of roof/façade on which PV can be placed (and assuming minimal overshading from surrounding buildings).

Other findings about the impact of development scale include that:

- Costs are also expected to be higher for smaller scale developments (because more cost effective site wide solutions are less applicable). Therefore, costs may be higher for smaller firms which would have a greater exposure to smaller scale developments.
- The highest levels of cost efficiency will be achieved on larger sites or where it is possible to aggregate small developments to a district scale which could facilitate either the involvement of ESCOs or Multi User Service Companies (MUSCOs).

Although not a scenario explicitly considered in this study, it is likely that mixed use sites, which can better support larger scale centralised systems, will find it easier to achieve the zero carbon standard.

Risks

The key influence on the financial viability of developments relates to the potential dislocation between developers exposure to higher capital cost and the ability to recoup this from either higher sales values (as homeowners capitalise the value of future savings in fuel bills). The majority of the policy costs may be borne by developers (or ultimately landowners) with homeowners receiving the additional benefits. The potential involvement of an energy services company (ESCO) could present a mechanism for financing the initial capital costs against the stream of future revenues, however in practice ESCO involvement in small sites or where technology paybacks are marginal could be difficult.

Adaptation to new technologies on a large scale will require re-training of existing labour, and recruitment of new operatives and installers to meet demand across the construction industry.

The structure of the market for electricity may also be influenced. At present, home owners have freedom of choice in respect of their energy suppliers. This freedom may be limited in future, where dwellings could conceivably be tied to a particular ESCO for heat (and potentially power). If ESCOs are to be encouraged to invest in new developments they will need some surety of future demand for electricity as well as heat if they are to raise finance effectively. At present the 28 day rule means that homeowners can change electricity suppliers rapidly. This is not too great a risk where the percentage of power generated on-site is relatively low, but as it increases towards net 100% it could become a far more significant issue.

The systems modelled are assumed to be based around a private wire distribution system[8]. These systems are generally more expensive to install but draw greater income from electricity sales. Nevertheless, sites will still need to be connected to the grid to provide supplies for peak demand and even if a site is net zero carbon over a year it will still need to draw on energy from the grid on a regular basis (replacing this energy at times of surplus). Given that the price of energy sold into the grid is governed by a number of factors such as timing, quantity and predictability it could be difficult for a single site to achieve significant revenue from energy sold into the grid. Therefore, uncertainty in the surety of demand and the inability to 'net meter' may act as a disincentive to ESCO involvement as the overall expectation of on-site generation rises to net 100%.

Priorities for further analysis

This is one of the first pieces of research to consider the implications of achieving zero carbon housing in England. Significant further work is required to address some of the key issues arising, including:

- The extent and conditions under which offsite renewable energy sources could be used to supplement/replace energy generated on-site
- The wider implications of encouraging the widespread adoption of biomass based technologies throughout the UK (eg fuel supply and pricing and impact on air quality)
- The integration of the predicted expansion of locally generated electricity within existing regulatory regimes (including export pricing and ability to change suppliers) and the Renewables Obligation as currently structured
- The role of ESCOs in delivering zero carbon developments.

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[8] This is where the ESCO owns and maintains the distribution infrastructure across the whole site and is therefore able to distribute power around the site without it passing through the grid. A private wire system (especially where there is a mix of uses) therefore enables a greater proportion of locally generated electricity to be used internally rather than exported to the national grid.

Section 1: Introduction

1.1 Background

This report describes research commissioned by the Department for Communities and Local Government into the possible implications of revising the current Part L1a of Building Regulations in 2010, 2013 and 2016 to impose progressively tighter restrictions on the carbon emissions of new dwellings, culminating in a requirement for all new housing to achieve zero carbon status from 2016.

The research considers the costs (capital and ongoing) and the benefits (financial and environmental) of achieving this target through a number of alternative policy options.

A dynamic cost model[9] is used to simulate the changes of costs and benefits over time, utilising learning rates (or experience curves) to estimate likely trends in technology cost.

The model input data is based upon projections for new build housing over the period 2008 to 2025, inclusive, categorised into four generic development types, and using four alternative dwelling types, considered representative of the planned development in England over this period.

The potential risks associated with the policy options considered, are identified, together with suggested priorities for further action prior to 2016.

To assess the risk of perverse impacts arising from the measures to reduce operational carbon emission from new housing, the embodied carbon in energy efficiency and LZC technologies is also considered.

The initial results of this research were used to inform the regulatory impact assessment of the *Building a Greener Future: Policy Statement* of July 2007. However, the results presented here are based upon updated house building projections. While the assessment method and key findings present here are consistent with those used in the *Building a Greener Future* regulatory impact assessment, the increased level of new house building in current Government projections means that the absolute costs and benefits are slightly greater.

Notwithstanding this, it should be noted that this is a technical rather than a policy document.

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[9] The dynamic cost model considers the level of uptake of each carbon saving technology in previous years when determining the likely costs for the year being modelled (see Section 2.2).

1.2 Research objectives

The research has five main objectives:

1. To improve the evidence base for, and understanding of, the technical measures that are likely to be applied to achieve 25% and 44% improvements over current Building Regulations in 2010 and 2013 respectively, and to achieve zero carbon in 2016.
2. To develop an understanding of the additional costs associated with meeting these carbon reduction standards for different types of development and how these costs might change over time.
3. To model the direct benefits that flow from the use of the technologies identified to achieve the target carbon reduction standards, including:
    a) Households, in the form of energy bill savings from use of renewable or LZC technologies and improved energy efficiency; and
    b) The environment, in terms of reduced carbon dioxide emissions.
4. To assess the sensitivity of these costs and benefits to different policy options or definitions of 'zero carbon', such as the allowing of some carbon saving to take place off-site.
5. To consider some of the associated implications of the policy options such as:
    a) The carbon embodied in the technological and design solutions required to achieve each carbon performance standard
    b) The impact of the policy on the future availability of biomass
    c) The potential contribution to the UK renewable energy target
    d) Possible, 'spill over' effects between new build dwellings and existing stock.

1.3 Limitations of the Research

The scope of the research is defined by the constraints of the current Building Regulations regime and relies on the use of current technologies, or those predicted to be available in the near future.

The dynamic cost model analyses the carbon reductions derived annually from new dwellings projected to be built in England and Wales for the period 2008 to 2025, inclusive.

These annual carbon reductions are then further projected to 2050 to give an indication as to the likely annual carbon reduction achievable at that date from the dwelling numbers modelled. It has been assumed that homes will retain their starting level of carbon performance throughout their lifespan. However, the costs and benefits of the associated technologies have only been measured until the end of the service life of the technology solution originally installed. Commentary is provided on the potential costs and benefits of replacement at some point post 2025. However, it is very difficult to make robust estimations over the long time periods involved.

The analysis assumes that in the absence of any policy intervention both the regulated and unregulated carbon emissions from new housing (as predicted using Standard Assessment Procedure (SAP) and the algorithms in set out in the Code for Sustainable Homes[10]) these emissions are assumed to be unchanged over the course of the study period.

Where the option of offsite generation is available as a means of reducing carbon emissions from new housing, it is assumed that sufficient capacity is available in the UK to meet the predicted requirements.

1.4 Research team

The research was led by construction cost consultants Cyril Sweett Limited, who also estimated build and operational costs. Energy modelling was carried out by engineer Faber Maunsell. The dynamic cost model was designed and constructed by the economics consultancy Europe Economics.

The steering group for the study comprised representatives of Communities and Local Government, DEFRA and the Cabinet Office.

1.5 Definitions

The following definitions are useful in interpreting the method and results of this study:

- Dwelling Emission Rate (DER) – the carbon dioxide emissions per m^2 of floor space arising from the provision of heating, hot water and lighting in a home (together with power for any pumps and fans involved in delivering these services)
- Embodied carbon – the carbon utilised in the extraction, manufacture and transportation of a product (in contrast to the carbon released or saved during its operational life)
- EST Best Practice – a suite of energy efficiency measures involving improved levels of thermal insulation and air tightness in new housing (see Table 2.7)
- EST Advanced Practice – a suite of energy efficiency measures involving greatly improved levels of thermal insulation and air tightness in new housing (see Table 2.7)

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[10] Communities and Local Government, 2007. *Code for Sustainable Homes, Technical Guidance*. October 2007.

- Heat Loss Parameter – a measure of the thermal efficiency of a building, defined as the heat losses per m^2 per degree Kelvin (W/m^2K).
- Learning rate – the rate at which the cost of a technology is predicted to fall each time the global market for a new technology doubles
- Low and zero carbon (LZC) technology – a technology that generates heat or power while emitting no or low levels of CO_2
- Policy compliance – the extent to which new homes are expected to comply with a particular policy requirement in a given year
- Regulated emissions – the domestic carbon dioxide emissions arising from sources that are regulated by Building Regulations Part L1a (see DER)
- Standard Assessment Procedure (SAP) 2005 – the standardised assessment method by which regulated emissions are calculated in line with Building Regulations
- Unregulated emissions – the domestic carbon dioxide emissions arising from sources that are not regulated by building regulations, ie appliances and cooking
- Zero carbon home – a home that, over a year, would have zero net carbon emissions from all energy use including appliances.

Other terms used in the study are explained, as they arise.

Section 2: Method

2.1 Overview

The research is based around the development of a dynamic cost model which selects the optimal[11] combination of measures required to achieve a specific carbon reduction against a baseline of Building Regulations Part L1a 2006.

The model analyses four generic development scenarios, representing the planned development in England, for the period from 2008 to 2025. Each development scenario is in turn built up from four generic dwelling types. The model analyses the costs and benefits for each year of the study period based upon an estimate of new build housing projections in England, with the costs of each technology dependent on the 2008 price, the estimated global market for the technology, the level of uptake in new housing as a result of alternative policy options and the learning rate of each technology.

To assess the implications of each policy option, a reference case and range of potential intervention cases were developed. The reference case reflects the assumed future 'business as usual' situation for all of the key variables assessed in the study, based upon the current Part L1a of the Building Regulations, and provides a point of comparison for the various intervention cases that could be used to implement the proposed policy.

For each policy option the model generates data comprising:

- The optimum technology mix to achieve the required standard in each modelled year; based either on an assessment of capital cost only or capital and operations cost combined
- The present value of capital costs above a Building Regulations Part L1a 2006 baseline
- The present value of ongoing costs arising from additional maintenance and plant replacement
- The present value of benefits arising from reduced energy costs
- The quantity of carbon saved per annum and in total (in tonnes)
- The present value of carbon savings (in £)
- The net present value of each policy option above a Building Regulations Part L1a 2006 baseline, taking costs and benefits into account (note: this figure is presented inclusive and exclusive of the present value of carbon savings)
- The change in technology cost resulting from changes in global market size and as a result of the policy option

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[11] The optimisation is based either exclusively on capital cost or a combination of capital cost and operating costs and benefits.

As uncertainty surrounds some elements of the input data, each policy option was also modelled using a range of higher values and separately a range of lower values compared to the base assumptions for key variables such as capital costs, benefits, learning rates and the value of carbon savings. The impact of this sensitivity analysis is discussed in Section 4.12.

2.2 Dynamic model

At the core of the model is a formula that seeks to find the most cost effective mix of technologies that will reduce the carbon emissions of a dwelling to the required standard in any given year. The selection process can be optimised in two ways. Firstly, assuming that a developer would base their decisions purely on capital cost, and secondly, assuming that they would consider both capital and ongoing costs and benefits.

The optimisation process is 'dynamic' in that the technologies selected in one year affect their predicted cost in the following year because of the influence of uptake on technology costs. The optimisation is carried out separately for each development type, dwelling type and sector (ie for affordable and open market housing) and year.

The dynamic model comprises the following elements:

- Input data
  - Housing projections
  - Composition of development scenarios
  - Dwelling types
  - Baseline (Part L1a 2006) energy and carbon projections for each dwelling type
  - Predicted percentage compliance with each policy option for each year
  - Policy standards for percentage improvement in regulated and unregulated carbon emissions for each year between 2008 and 2025
  - Build costs; based upon four dwelling types across four development types
  - Carbon saving options, including energy efficiency measures and renewable energy technologies. For each dwelling type, information is included for:
    - The sizing of each technology within maximum and minimum limits
    - Applicability for different dwelling or development types
    - Compatibility with other technologies

    - Carbon savings[12]
    - Capital cost
    - Ongoing costs and benefits
    - Limits to overall level of application in any given year
  - Applicability of off-site solutions
  - Learning rates for each technology separated into global and local learning rates
  - Financial value of carbon savings using DEFRA guidance on the Shadow Price of Carbon
  - Carbon intensity of grid electricity
  - Domestic energy prices
- The Optimisation module
- Results (by dwelling type, development type and overall), comprising
  - Technology mix
  - Capital cost
  - Ongoing costs
  - Benefits
  - Carbon savings
  - Change in energy consumption by fuel type,

All results are presented as present values using a discount rate of 3.5%.

The working of the model is summarised in Figure 2.1. Each of the key components is described in more detail in the remainder of this section.

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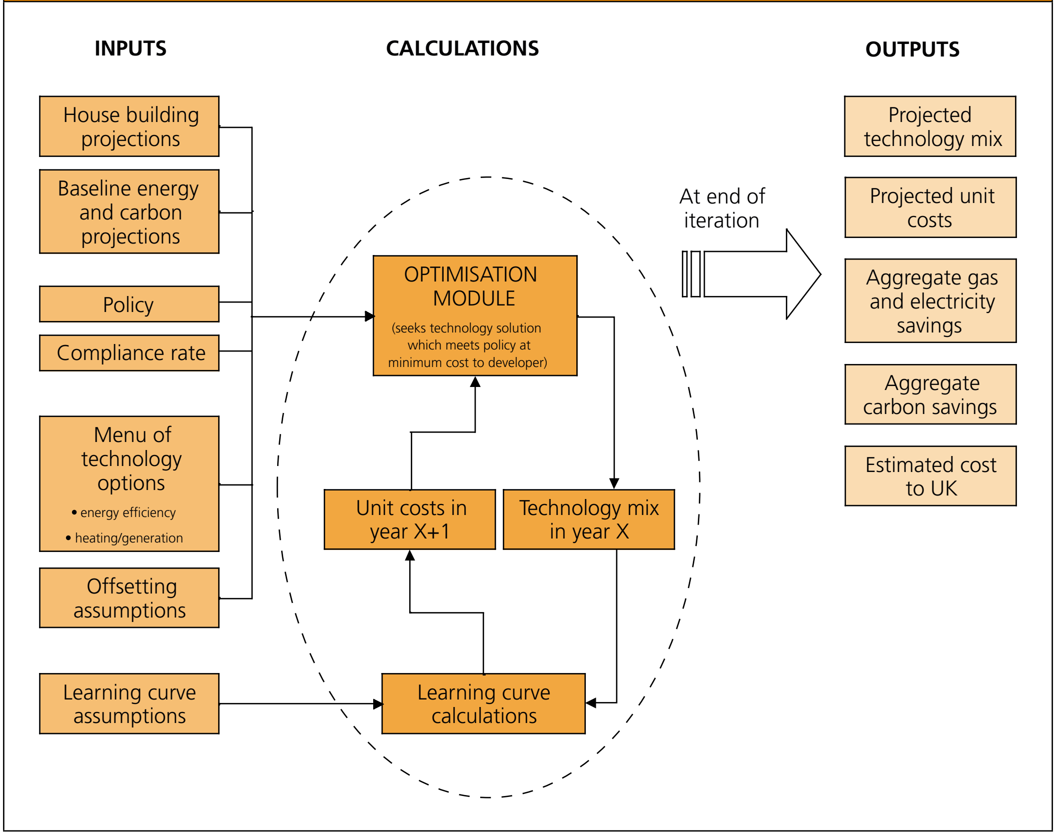
[12] Because the carbon savings from some energy efficiency and LZC options are linked (ie the savings from use of biomass heating system will depend on the thermal efficiency of the house) it was necessary to model the carbon savings for LZC technologies against three levels of energy efficiency performance (Part L 2006, EST Best Practice and EST Advanced Practice).

Figure 2.1: Summary of dynamic cost and benefit model



2.3 Input Data

The key model input data are described below, further information on the source of this information is presented in Appendix A.

2.3.1 Housing projections

Projections of total new housing completions by housing type and tenure were derived from Communities and Local Government housing statistics on new permanent dwellings together with the estimated number of new build associated with the *Housing Green Paper* target to achieve 240,000 net additional dwellings per annum by 2016. Table 2.1 shows the estimated total numbers of new housing by house type between 2008 and 2025.

Table 2.1: Estimated total new housing completions between 2008 and 2025 (England)

Year	Total completions per year	Houses (68%)	Flats (32%)
2008	171,088	116,785	54,303
2009	173,618	118,512	55,106
2010	176,364	120,386	55,978
2011	179,099	122,253	56,846
2012	184,792	126,139	58,653
2013	189,299	129,215	60,084
2014	194,969	133,086	61,883
2015	205,830	140,500	65,330
2016	219,083	149,546	69,537
2017	219,083	149,546	69,537
2018	219,083	149,546	69,537
2019	219,083	149,546	69,537
2020	219,083	149,546	69,537
2021	219,083	149,546	69,537
2022	219,083	149,546	69,537
2023	219,083	149,546	69,537
2024	219,083	149,546	69,537
2025	219,083	149,546	69,537

Source: Communities and Local Government statistics.

2.3.2 Composition of development scenarios

To test the achievability of each policy option on different types of development, four development scenarios are used:

- Small Scale
- City Infill
- Urban Regeneration
- Market Town

The four scenarios represent a range of development sizes, densities and housing types, as shown in Table 2.2.

Table 2.2: Composition of each development scenario

Scenario	Density (dwell/ha)	Site Area (ha)	Dwelling Types	Nos.	Dwelling Mix	Percentage of Social housing
Small Scale	30	0.3	Detached	4	45%	20%
			Terrace	3	33%	
			End-t/semi	2	22%	
			Flat	0	0%	
			Total	**9**	**100%**	
City Infill	180	0.1	Detached	0	0%	20%
			Terrace	0	0%	
			End-t/semi	0	0%	
			Flat	18	100%	
			Total	**18**	**100%**	
Market Town	50	2	Detached	25	25%	20%
			Terrace	27	27%	
			End-t/semi	21	21%	
			Flat	27	27%	
			Total	**100**	**100%**	
Urban Regeneration	160	4.7	Detached	30	4%	20%
			Terrace	15	2%	
			End-t/semi	8	1%	
			Flat	697	93%	
			Total	**750**	**100%**	

2.3.3 Dwelling types

The dwellings used in each development scenario are based on current housing types and construction methods typically used in England with baseline energy performance compliant with current Building Regulations. Key assumptions used to determine the baseline performance of each dwelling type are presented in Table 2.3. Some of the carbon saving measures applied to these dwellings (eg energy efficiency measures) could involve changes to either the design or construction method of the homes, but no wholesale design changes were considered.

Table 2.3: Base specifications for each dwelling type

Parameter	Detached	End terrace/ semi	Mid terrace	Flat
Internal floor area (m^2)	102	76	76	60
Area available for solar installation per dwelling (m^2)	58	38	38	20
U Values ($W/m^2/K$)				
Floor	0.22			
Exposed walls	0.28			
Roof	0.14			
Windows	1.71			
Half glazed door	1.79			
Fully glazed doors	1.71			
Solid Doors	0.99			
Thermal bridging	0.08			
Ventilation	Natural ventilation – fans in kitchens and bathrooms			
Air tightness ($m^3/m^2/hr$)	8			
Heating				
System	Central heating with radiators			
Gas condensing boiler efficiency	90.2%			
Controls	Delayed start thermostat, cylinder stat, programmer, TRVs			
Hot water				
Hot water storage volume	160			
Hot water cylinder loss factor	0.015			
Lights	30% Low Energy			
Cooking and Appliances	Estimated using formulae used in Code for Sustainable Homes Technical Guide (September 2007). It was assumed that gas appliances would be provided for cooking.			

The selected dwelling types provide a cross section of 'housing variables' such as size, proportion of exposed wall, floor and roof area, overall roof area, occupation levels, etc. and illustrate the range of different dwelling types to which the proposed policy will apply. The house types used in this study represent only a small selection of the numerous dwelling types built each year, including bungalows, mews houses, houses with integrated garages, and town houses. Nonetheless, data on housing registrations suggests that the four dwelling types used in this research reflect the vast majority of new house building in England and Wales.

2.3.4 Housing projections by dwelling type and development scenario

The indicative breakdown of housing completions by development scenario used in this research is shown in Table 2.4. This breakdown is based on information received from the National House Building Council (NHBC) on housing registrations in 2006 by dwelling type and development size.

Table 2.4: Breakdown of housing completions between development scenarios

Scenario	Percentage of completions
Small Scale	15%
City Infill	3%
Market Town	72%
Urban Regeneration	10%

Source: data provided from NHBC registration statistics for 2006.

Using the breakdown shown in Table 2.4, together with the indicative composition of each development scenario, from Table 2.2, the number of units of each dwelling type built in each year is calculated as shown in Table 2.5.

Table 2.5: Predicted completions by dwelling type and development scenario

	Small Scale				City Infill				Market Town				Urban Regeneration			
Year	**Detached**	**End terrace/ semi-detached**	**Mid terrace**	**Flat**	**Detached**	**End terrace/ semi-detached**	**Mid terrace**	**Flat**	**Detached**	**End terrace/ semi-detached**	**Mid terrace**	**Flat**	**Detached**	**End terrace/ semi-detached**	**Mid terrace**	**Flat**
2008	11,548	5,646	8,469	–	–	–	–	5,133	30,796	25,869	33,260	33,260	684	171	342	15,911
2009	11,719	5,729	8,594	–	–	–	–	5,209	31,251	26,251	33,751	33,751	694	174	347	16,146
2010	11,905	5,820	8,730	–	–	–	–	5,291	31,746	26,666	34,285	34,285	705	176	353	16,402
2011	12,089	5,910	8,865	–	–	–	–	5,373	32,238	27,080	34,817	34,817	716	179	358	16,656
2012	12,473	6,098	9,147	–	–	–	–	5,544	33,263	27,941	35,924	35,924	739	185	370	17,186
2013	12,778	6,247	9,370	–	–	–	–	5,679	34,074	28,622	36,800	36,800	757	189	379	17,605
2014	13,160	6,434	9,651	–	–	–	–	5,849	35,094	29,479	37,902	37,902	780	195	390	18,132
2015	13,894	6,792	10,189	–	–	–	–	6,175	37,049	31,121	40,013	40,013	823	206	412	19,142
2016	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2017	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2018	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2019	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2020	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2021	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2022	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2023	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2024	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375
2025	14,788	7,230	10,845	–	–	–	–	6,572	39,435	33,125	42,590	42,590	876	219	438	20,375

2.3.5 Baseline energy demand and carbon emissions

Baseline regulated energy demand and carbon emissions from each dwelling type are estimated using an approved SAP 2005 energy model[13] (NHER Plan Assessor). Regulated carbon emissions relate to energy used for heating, hot water, pumps, ventilation and lighting.

Unregulated carbon emissions (ie emissions from cooking and use of appliances) were estimated using the formulae published in the Code for Sustainable Homes: Technical Guide (September 2007).

Regulated and unregulated carbon emissions and energy consumption calculated for each dwelling type are shown in Table 2.6.

Table 2.6: Baseline energy consumption and carbon emissions

Dwelling type	Energy consumption kWh (regulated energy only)			Regulated carbon emissions (t per year)	Unregulated carbon emissions (t per year)	Total emissions (t per year)
	Electricity	**Gas**	**Biomass**			
Detached	3,922	10,029	0	2.34	1.26	3.70
End-terrace/ semi	3,144	7,604	0	1.70	1.11	2.81
Mid-terrace	3,072	6,809	0	1.51	1.11	2.62
Flat	2,486	6,344	0	1.35	0.92	2.27

It is likely that the nature of both regulated and unregulated carbon emissions from housing will change over the course of the modelled period (ie 2008 to 2025). Potential reasons could include changes in:

- Building Regulations calculation methods (for example, changes in assumptions regarding the use of low energy light fittings and secondary heating)
- The level of unregulated carbon emissions associated with appliance use

Nevertheless, the aim of this research is to assess the impact of the carbon reduction policy within the current regulatory regime and, therefore, the above changes have not been considered.

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[13] As a result the analysis also assumes that 10% of baseline heat demand will be met by electric heating and that no more than 30% of light fittings can be energy efficient.

2.3.6 Policy Compliance

It is assumed that 100% compliance with any policy change is achieved in the year following its implementation, ie all dwellings built in 2011 would achieve Building Regulation standards set in 2010. In reality, some dwellings built in 2010 would achieve the 2010 standard and some dwellings might be built to pre 2010 standards for 2 to 3 years after the change in Regulations; however a period of one year for implementation is considered a reasonable assumption based on responses to previous changes in regulation.

2.3.7 Carbon reduction options

At the core of this research is the development of a series of representative carbon reduction options for which the costs and benefits arising in different development scenarios could be assessed. The carbon reduction options considered included both energy efficiency measures and renewable energy technologies. For each carbon reduction option, analysis was undertaken to determine:

- Applicability to dwellings in different development scenarios and any other constraints on its use
- Appropriate sizing of technologies for each scenario
- Compatibility with other carbon reduction options
- Carbon savings – where available, the assumptions in SAP 2005 were used to determine technology performance. For technologies not covered by SAP 2005 the assumptions used to estimate carbon savings are stated in Appendix B.
- Capital and ongoing costs
- Benefits from energy savings

The options considered, either individually or as part of a package of measures, to achieve compliance with the relevant performance standards are shown in Table 2.7. Further information on each technology option is presented in Appendix B.

Table 2.7: Carbon reduction options

Option	Specification
Energy efficiency measures	
Energy Saving Trust Best Practice minimum design standards	Enhanced U values for floor (0.2 W/m^2/K), exposed walls (0.25 W/m^2/K), windows (1.6 W/m^2/K) together with air tightness of 3 m^3/m^2/hr and a 91.2% efficient boiler.
Energy Saving Trust Advanced Practice minimum design standards	Enhanced U values for floor (0.15 W/m^2/K), exposed walls (0.15 W/m^2/K), windows (0.8 W/m^2/K) together with air tightness of 1 m3/m^2/hr, whole house mechanical ventilation (fan power of <1w/s) and heat recovery (89% efficient) and a 91.2% efficient boiler.
Solar water heating	Options considered: • 2.8 kWp (aperture area of ~4 m^2) for detached housing • 2.3 kWp (aperture area of ~3.5 m^2) for terraced housing • 2.0 kWp (aperture area of ~3 m^2) for flats Each system was designed to work with cylinder storage and to be installed orientated to the south at an angle of 30°.
Photovoltaics	A range of PV array sizes were used, up to 4 kWp for each home. 1 kWp is assumed to cover 7.5 m^2 and to generate 781 kWh of electricity per year when orientated to the south at an angle of 30°. For flats, it was assumed that a combined system could be used for a group of units with array sizes of up to 24 kWp for the flat type considered in the study (bespoke architecture might enable greater quantities of PV to be used).
Biomass heating	Biomass communal heating system (88% efficient) sized to meet either 40% or 80% of total annual heat demand, serving radiators in each dwelling. Back up heating from gas boilers. Efficiency of heat distribution was assumed to be 95%.
Ground source heat pumps	Two types of system were considered: • a standalone system, where the heat pump supplies 100% of space heating and hot water. A co-efficient of performance of 3.2 was assumed for space heating and 2.24 for hot water • A communal system (for the City Infill scenario), where the heat pump meets 80% of space heating and hot water demand with back up from gas boilers. A co-efficient of performance of 3.2 was assumed for both heating and hot water, reflecting the role of the gas boiler in providing additional water heating. The heat pump options were all assumed to serve underfloor heating systems.
Combined heat and power systems (gas and biomass fired)	All of the CHP options were modelled as meeting either 40% or 80% of the total head load for the Market Town and Urban Regeneration scenarios, for each energy efficiency level. For the City Infill and Small Scale scenarios, only the 80% option was considered. A load factor of 0.5 was assumed for the 40% option and of 0.3 for the 80% option. A range of performance figures were used to reflect the characteristics of both biomass and gas fired systems used at different scales. These specifications are described in Appendix B.
Wind power	
Small Scale wind turbines (1.5kW)	Generating 1,100 kWh per annum.
Medium scale wind turbines (50kW)	Load factor of 0.15.
Large scale wind turbines (2 MW)	Load factor 0.2.

In addition to the above on-site technologies, off-site electricity generation is also considered in a number of policy options. In these instances, off-site renewable energy generation is assessed on the basis of a contribution (valued through ROC payments) to an off-site generation source with no design or technical impact on either the housing or site wide infrastructure (see Section 2.3.13)

2.3.8 Technology sizing and applicability

To achieve the required carbon reductions the model selects an appropriate quantity of each option to create an 'optimal' solution. To ensure this did not result in unrealistically small or large applications of an option, eg a 1 kW biomass boiler or 100 m^2 of PV on a roof only able to hold 30 m^2, each technology was sized according to the dwelling type and development scenario. For the energy efficiency options and communal systems only one size was allowed per dwelling in each scenario (ie the option was either used, or not used, with no variation in size), while for PV, medium scale wind and large scale wind, a size scale was used between minimum and maximum thresholds.

The model also constrained the specific technologies considered applicable to each development scenario. For example, because of concerns about the ability to achieve required wind speeds, micro wind turbines are only considered applicable for rural 'Small Scale' developments. Similarly, biomass CHP was not considered applicable to 'Small Scale' development because of the difficulties in sourcing a biomass CHP system to supply less than 10 dwellings.

Further, to make the analysis as realistic as possible, a restriction was placed on the number of developments that could make use of wind power. This acknowledges the limitation of using large scale wind generation on many sites within England and Wales, either because of lack of sufficient wind or planning constraints. The use of these technologies was constrained to a maximum of 20% of the developments to which they are considered applicable (ie Market Town and Urban Regeneration). The constraints on wind power only applied where the wind technology was to be located on-site (or locally via a private wire) and did not apply to 'off-site' renewable energy (considered under policy options 3(a) and 4(a).

Table 2.8 summarises the application constraints used in the model.

Table 2.8: Applicability and sizing constraints for each carbon reduction option

Technology	**Small Scale**	**City Infill**	**Market Town**	**Urban Regeneration**	**Max applicable percentage of sites**
Energy efficiency measures (Best and Advanced practice)	Yes	Yes	Yes	Yes	No limit
Solar water heating	Between 1.96 and 2.8 kWp per dwelling				No limit
Photovoltaics	0.5 to 4 kWp per dwelling	5 to 24 kWp per site (between 0.25 and 1.33 kWp per dwelling)	0.5 to 4 kWp per dwelling	0.5 to 4 kWp per dwelling	No limit
Biomass heating	10 kWth per dwelling	25 to 50 kWth per site	500 to 1000 kWth per site	500 to 1500 kWth per site	No limit
Ground source heat pumps	3-5 kWth per dwelling	25 to 50 kWth per site	500 to 1000 kWth per site	500 to 1500 kWth per site	No limit
Gas combined heat and power	8 to 12 kWe per site	8 to 12 kWe per site	100 to 500 kWe	1000 to 1500 kWe	No limit
Biomass combined heat and power	Not applicable	2 kWe* per site	100 to 500 kWe	1000 to 1500 kWe	No limit
Small Scale wind turbines (1.5kW)	1.5 kWp	Not applicable	Not applicable	Not applicable	No limit
Medium scale wind turbines (50kW)	Not applicable	Not applicable	20 to 150 kW	20 to 150 kW	Maximum of 20% of applicable sites
Large scale wind turbines (2 MW)	Not applicable	Not applicable	Not applicable	500 to 2000 kW	Maximum of 20% of applicable sites

Note:

*The Biomass CHP system used in the Small Scale and City Infill scenarios has a very high heat to power ratio (15:1) as a result the electrical output of these systems is smaller than for the gas CHP system.

2.3.9 Technology compatibility

In selecting the optimum technology combinations, the model discounts combinations of technologies deemed to be incompatible. For example, the EST Advanced Practice energy efficiency option is an extension of the EST Best Practice option, and therefore, both cannot be applied to the same dwelling at the same time.

The full list of compatibilities is shown in Table 2.9.

Table 2.9: Compatibility between carbon saving technologies

Technology	EST Best Practice	EST Advanced Practice	Solar water heating	Photovoltaics	Biomass heating	GSHP	Gas CHP	Biomass CHP	Small scale wind (1.5kW)	Medium scale wind (50kW)	Large scale wind (2 MW)
EST Best Practice standard	■										
EST Advanced Practice	✗	■									
Solar water heating	✓	✓	■								
Photovoltaics	✓	✓	✓	■							
Biomass heating	✓	✓	✗	✓	■						
GSHP	✓	✓	✗	✓	✗	■					
Gas CHP	✓	✓	✗	✓	✗	✗	■				
Biomass CHP	✓	✓	✗	✓	✗	✗	✗	■			
Small scale wind (1.5kW)	✓	✓	✓	✓	✓	✓	✓	✓	■		
Medium scale wind (50kW)	✓	✓	✓	✓	✓	✓	✓	✓	✗	■	
Large scale wind (2 MW)	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	■

Notes:

In practice it is possible (although relatively rare) to combine solar water heating systems and other heating systems (eg biomass/CHP etc). However because the benefits of adopting two thermal technologies are not additional these options were not combined in the model.

2.3.10 Carbon savings

The carbon savings arising from use of each of the technology options was modelled using SAP 2005 approved software[14]. For some LZC technologies (ie those that generate heat energy) the carbon savings achieved from their application is dependent on the thermal efficiency of the building envelope. To reflect this, each LZC technology was modelled against each of the three energy efficiency levels (Part L1a 2006, EST Best Practice, and EST Advanced Practice).

Table 2.10 shows the carbon savings associated with each technology option.

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[14] It is not possible to model the benefit of energy generated from wind turbines in SAP, the carbon saving from these technologies was estimated based on the kWh generation and a carbon emission factor of 0.56 kg CO_2 per kWh (the factor used in SAP for energy displaced from the grid).

Table 2.10: Carbon savings achieved per unit (kg CO_2 per annum)

Technology		House type											
		Detached			End terrace			Mid terrace			Flat		
Energy efficiency level	**Unit**	**Part L**	**EST Best**	**EST Advanced**	**Part L**	**EST Best**	**EST Advanced**	**Part L**	**EST Best**	**EST Advanced**	**Part L**	**EST Best**	**EST Advanced**
EST Best Practice standard	kg CO_2 Per home	240			200			139			173		
EST Advanced Practice	kg CO_2 Per home	610	370		417	217		291	152		329	156	
Solar water heating	kg CO_2 kWth	88			99			97			101		
Photovoltaics	kg CO_2 kWe	444											
Biomass heating*	kg CO_2 kWth	506-848			511-884			513-887			515-886		
GSHP*	kg CO_2 kWth	128-392	120-392	85-395	116-410	109-417	75-431	108-416	101-420	70-433	107-424	100-433	100-452
Gas CHP*	kg CO_2 kWe	699-1239			711-1288			715-1291			727-1291		
Biomass CHP*	kg CO_2 kWe	2325-3885			2336-3957			2340-3962			602-3962**		
Small scale wind (1.5kW)	kg CO_2 kWe	435											
Medium scale wind (50kW)	kg CO_2 kWe	746											
Large scale wind (2 MW)	kg CO_2 kWe	995											

Notes:

* the range in figures for centralised carbon saving technologies (eg biomass heating, GSHP, Gas CHP and biomass CHP) is a reflection of the different scales at which this technology can be employed, ie scaled to meet 40% or 80% of the heating and hot water demand.

** the relatively small minimum carbon saving achieved from a Biomass CHP for flats reflects the use of a small Stirling engine system for the City Infill scenario, this system has a high heat to power ratio of 15 to 1 (rather than 2 to 1 typical of other CHP engines) and is therefore less efficient in saving carbon than larger installations (because less electricity is generated by meeting the thermal demand). For larger scale applications (ie on the Market Town and Urban Regeneration scenarios) the performance range of a biomass CHP in flats is similar to that for housing.

Source: Derived from modelling using SAP 2005 compliant software.

2.3.11 Capital costs

The capital costs of each technology option were estimated separately for each dwelling type[15] within each of the four development scenarios.

The costs represent an estimate of the total costs to a contractor, including materials, plant and labour, builder's work in connection, preliminaries, overheads, contingencies, profit, and design fees.

The costs relate to the construction of the dwellings only, and therefore, make no specific allowance for items which would by their nature be site specific, such as site works and common infrastructure (other than where this is required for communal systems).

By way of example, the costs for the combined heat and power systems include boilers, buffer vessels, pumps, power, flues, heating pipework within plant rooms, external distribution pipework, external trenches and backfill, distribution mains, heat exchangers and hydraulic boards within dwellings.

The costs for ground source heat pump systems also include underfloor heating loops and manifolds within dwellings.

The costings exclude the following:

- Site acquisition costs
- Professional fees, other than design fees incurred by the contractor
- Party wall awards and any work in connection therewith
- Building Control and planning fees
- Any payments which may be required under Section 106 of the Town and Country Planning Act
- Remediation of site contamination
- Survey works
- Legal fees
- Finance costs
- Loose furniture and fittings, such as curtains, blinds, shelving, furniture and kitchen appliances
- Highways works
- Value Added Tax

[15] Costs were also determined for each home's energy efficiency level where this was relevant to the sizing and performance of the technology.

The costings are current at Q4 2007 price levels, as built by a contractor with a trading turnover of around 5,000 to 10,000 dwellings per annum.

Wherever possible, the costs have been based upon quotations received from contractors and suppliers.

Capital costs may vary considerably depending on the size of the installation. This is reflected in the model, by scaling applicable technologies, such as PV, into bands broadly consistent with the development scenarios selected.

Table 2.11 summarises the ranges of capital costs of each technology option.

Table 2.11: Capital cost of each carbon saving option when applied to a Part L1a 2006 compliant home

Technology option	Scale (if applicable)	Unit	£/unit (minimum)	£/unit (maximum)
Solar Water Heating	Generally 2.8m² of flat panel collector per dwelling	m²	£850	£850
PV	Scaled from 0.25kWp to 4kWp per dwelling	kWe	£4,200	£4,800
Biomass Heating	Scaled on biomass boiler capacities from 25kW to 1,000kW	kWt	£200	£600
Ground Source Heat Pumps	Scaled on GSHP capacities from 250kW to 500kW	kWt	£800	£2,750
Biomass CHP	Scaled for biomass CHP capacities (large sites)	kWe	£3,500	£3,500
	Scaled for biomass CHP capacities (small City Infill sites)	kWe	£16,000	£16,000
Gas Fired CHP	Scaled on CHP capacities from 8kWe to 40kWe	kWe	£1,200	£3,400
	Scaled on CHP capacities over 400kWe	kWe	£650	£1,200
Micro Wind	Generally based on 1.5kW unit per dwelling	kWe	£2,500	£2,500
Medium Wind	Scaled in units 150kW to 600kW	kWe	£1,250	£1,500
Large Wind	Scaled in units 600kW to 1,200kW	kWe	£900	£1,250

Source: Cyril Sweett research and survey of suppliers and installers.

2.3.12 Ongoing costs and benefits

The ongoing costs associated with each carbon saving technology option were calculated based upon expected maintenance, operational (ie servicing) requirements and component replacement over the estimated service life.

The maintenance costs of each technology were estimated to reflect an average assessment of likely component failure and maintenance requirements. Clearly, significant variance could arise, dependent upon such factors as location and prevailing environmental conditions.

The costs for component replacement allow for the supply and installation of the component itself, re-cabling and/or new connections (as applicable), and an assessment of the associated builder's work in connection, site preliminaries, labour, design costs, overheads and profit.

The cost for maintenance include for periodic inspections for cleaning and general maintenance.

All ongoing costs are discounted back to their current present value.

Table 2.12 summarises the service life, and maintenance assumptions adopted against each technology option.

Table 2.12: Service life and maintenance assumptions used as basis of ongoing cost of each carbon saving option

Technology	Service life	Maintenance/Renewal	Servicing
Solar Water Heating	29yrs	Part overhaul at year 5; replacement of minor components valves, pumps AAV's Annual topping up of antifreeze/ corrosion inhibitors	Annual inspection in conjunction with the gas fired boiler Minor adjustments and repairs
PV	26yrs	Replacement of supporting cabling infrastructure, supports and associated controls at the point where significant reductions in system performance have occurred	Annual inspection Replacement of failed system components by Specialist
Biomass Community Heating	19yrs	Part overhaul every 5 years Major component replacement at year 10 distribution pipe work expected to last beyond the service life of the boilers	Monthly inspection of boiler plant and associated plant with remote monitoring facilities

Table 2.12: Service life and maintenance assumptions used as basis of ongoing cost of each carbon saving option *(continued)*

Technology	Service life	Maintenance/Renewal	Servicing
Ground source heat pumps	29 yrs	Part overhaul of plantroom pipework every 5 years Part replacement of underfloor heating system at years 10 and 20 Part overhaul of GSHP's at years 10 and 20 Part overhaul of boilers and electrical connections at years 15 and 25 Overhaul of external; distribution pipework and heat exchanger at year 20	Annual inspection Minor adjustments and repairs
Biomass community Combined Heat and Power System	19 yrs	Part overhaul every 5 years Major component replacement at year 10 Distribution pipe work expected to last beyond the service life of the boilers	Monthly inspection of boiler and associated plant with remote monitoring facilities
Gas community Combined Heat and Power System	19 yrs	Part overhaul at years 5, 10, 15 Replacement of CHP installation after 19 yrs Distribution pipe work expected to last beyond the service life of the boilers.	Monthly inspection of boiler plant and associated plant with remote monitoring facilities and omission of annual domestic boiler service
Micro Wind	19 yrs	Part overhaul at year 10 Replacement after 19 yrs	Bi annual inspection of installation Minor adjustments and repairs
Medium Wind Turbines	29 yrs	Part overhaul after 10 years; replace installation after 29 yrs of usage	Annual inspection of installation Minor adjustments and repairs
Large Wind Turbines	29 yrs	Part overhaul after 10 years; replace installation after 29 yrs of usage	Annual inspection of installation minor adjustments and repairs

Source: Cyril Sweett research and survey of suppliers.

Table 2.13 provides an indication of the net savings in energy costs and the net change in operational and maintenance costs for each technology option on the basis of the assumptions contained in Table 2.12. The figures are presented on a present value basis as a sum per tonne CO_2 saved. Clearly, the figures vary depending upon a number of factors such as dwelling type, development scale, mix and location, and further, the benefits vary according to the displaced energy requirements (ie electricity or gas) and whether an ongoing fuel cost is present (eg in the case of gas CHP or biomass heating/CHP systems). For illustrative purposes, this table represents the results for a detached house.

Table 2.13: Estimated costs and benefits of each carbon saving technology option for a Part L1a 2006 compliant detached house

Technology	Present value* of saving in energy costs (£/tonne CO_2 saved)	Present value* of operating and maintenance costs (£/tonne CO_2 saved)**	Net present value* of ongoing costs and benefits (£/tonne CO_2 saved)
Solar Water Heating	£2,324	–£131	£2,193
PV	£2,579	–£663	£1,916
Biomass Heating	£968	£2,279***	£3,247
Ground Source Heat Pumps	£807	£6,026***	£6,833
Biomass CHP	£1,223	£1,202***	£2,425
Gas Fired CHP	£2,728	£2,168***	£4,896
Micro Wind	£2,137	–£1,037	£1,100
Medium Wind	£2,829	–£349	£2,480
Large Wind	£2,829	–£154	£2,675

Note:

* Present value assessed over the service life of the technology (see Table 2.12) with a discount rate of 3.5%

** Negative numbers represent a net cost in comparison to a typical Part L1a compliant dwelling

*** Positive numbers represent a net benefit in comparison to a typical Part L1a compliant dwelling. In the case of heat pumps the significant benefit results from the much lower maintenance costs of associated underfloor heating systems.

The benefits of each technology option were considered purely in terms of net savings in energy costs (in comparison to current domestic tariffs). No benefit associated with the sale of ROCs or any other carbon pricing mechanism is considered as it is assumed that technology installed to meet Building Regulations requirements would not be eligible for such benefits which would compromise the additionality of the achieved carbon savings.

Fuel cost projections for electricity and gas were based upon those used in the Energy Saving Trust, Econnect and Element Energy Report *Potential for Microgeneration Study and Analysis*, ie £0.089 per kWh for electricity and £0.025 per kWh for gas.

Fuel projections for biomass wood chip were based upon a rate of £0.016 per kWh as currently used in approved SAP 2005.

The sensitivity of the results to different energy price scenarios was tested using high and low estimates from DTI (now BERR) projections.

The extent to which the above benefits, after accounting for obligations to the ongoing costs, would accrue directly to homeowners is considered in section 5.

2.3.13 Off-site renewable energy

For several of the policy options considered in the research it was necessary to allow use of dedicated off-site renewables. The cost of providing off-site renewables was estimated using ROCs as a proxy for the level of contribution that might be expected from a developer in order to construct dedicated additional capacity. To ensure additionality, the new renewable capacity would not be eligible for ROCs and therefore it would be necessary for the home builder to compensate the renewable energy developer for this lost revenue in order to ensure the financial viability of the new capacity.

The value of the payment required from a developer is assumed to be equivalent to the present value of 29 years of ROCs; equivalent to the life expectancy used in this research for large scale wind; the technology most likely to be generating the off-site energy supply.

The achievability of delivering sufficient off-site capacity to reduce the carbon emissions of new housing was outside the scope of this research, as was any potential for supply shortages which might impact the likely costs of reducing carbon via this route.

2.3.14 Learning rates

The model uses learning rates to estimate how the costs of each technology may change over time.

Learning rates are the extent to which the relative costs of a technology change over time in proportion to the size of the market for the technology. Learning rates are derived from empirical studies that have demonstrated ongoing trends in the costs of a technology arising from ‘learning’ in its broadest sense (eg in the form of technological advance, production efficiencies, improved design, supply chain management, etc). Learning rates are typically presented as a percentage reduction in cost that occurs with each doubling of the market.

Learning can occur on at both global and local levels. Global learning relates to the global price for a particular technology and is influenced by the size of the global market. Local learning relates to the elements of cost that are influenced by local markets. For example, labour costs will be driven by the familiarity of local businesses with the technologies involved and the extent to which this will influence their costs for installation, maintenance and servicing. In this research the capital and ongoing costs of each of the carbon saving options are split into those believed to be driven by global learning rates and those driven by local learning. Table 2.14 summarises the global and local learning rates used for each technology option.

Table 2.14: Learning rates

Carbon Saving Technology Option	Global Learning Rate			UK Learning Rate		
	High	Medium	Low	High	Medium	Low
EST Best practice	1%	3%	5%	1%	3%	5%
EST Advanced practice	3%	15%	21%	1%	3%	5%
Solar Water Heating	1%	10%	18%	1%	3%	5%
PV	18%	18%	25%	1%	3%	5%
Biomass Community Heating	15%	15%	20%	1%	3%	5%
Ground Source Heat Pumps	5%	9%	15%	1%	3%	5%
Biomass CHP	20%	20%	25%	1%	3%	5%
Gas CHP	5%	9%	4%	1%	3%	5%
Micro Wind	5%	5%	18%	1%	3%	5%
Medium scale Wind	4%	10%	10%	1%	3%	5%
Large scale Wind	4%	10%	10%	1%	3%	5%

Changes in cost could be driven by the policy under consideration (endogenous factors) or by external (exogenous) factors such as global trends in market size or other unrelated policies (such as the use of renewable energy to satisfy Planning Authority requirements for minimum levels of on-site renewable energy generation 'Merton Rule'). For each year that the model is run, the cost of each technology option is adjusted based on the relative size of global and local markets in comparison to the base year and the learning rate for the technology. The cost of each technology option is therefore different in each year for which the model is run, this cost being influenced both by endogenous and exogenous factors.

By removing cost reductions arising from exogenous market growth it is possible to determine how much of the changes in cost arising from the model might be said to have resulted from the impact of policy.

It is important to remember that learning rates only provide a theoretical projection of price trends and that other factors such a changes in the costs of primary materials or step changes in technology will also influence actual costs.

2.3.15 Shadow price of carbon

To establish the absolute net cost or benefit of each policy option, the model also estimates the value of the social benefit of the resulting carbon reductions. This is based upon DEFRA guidance on the Shadow Price of Carbon[16]. The 2007 price of £25 per tonne of carbon dioxide with a 2% per year escalator (reflecting the benefit of early rather than delayed action to reduce emissions). Table 2.15 shows the value for the Shadow Price of Carbon used in this study presented as £/tonne CO_2.

Table 2.15: L Shadow Price of Carbon (£/ tonne CO_2)

Year	High scenario	Medium scenario	Low scenario
2008	12.82	25.63	51.27
2009	13.07	26.15	52.29
2010	13.33	26.67	53.34
2011	13.60	27.20	54.41
2012	13.87	27.75	55.49
2013	14.15	28.30	56.60
2014	14.43	28.87	57.74
2015	14.72	29.45	58.89
2016	15.02	30.03	60.07
2017	15.32	30.64	61.27
2018	15.62	31.25	62.50
2019	15.94	31.87	63.75
2020	16.26	32.51	65.02
2021	16.58	33.16	66.32
2022	16.91	33.82	67.65
2023	17.25	34.50	69.00
2024	17.60	35.19	70.38
2025	17.95	35.89	71.79

Source: DEFRA, 2007

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[16] DEFRA, 2007. How to use the Shadow Price of Carbon in policy appraisal. August 2007.

The reference to high, medium and low scenarios in the table denotes the range of potential variance in the cost for the purposes of testing the sensitivity of the model results. This is discussed in more detail in Section 5.

2.4 Output data

Key outputs upon which analysis is based

The key outputs from the model, analysed in this report, are;

- Total estimated costs and benefits resulting from each policy option; in £m or £ per tonne CO_2 saved
- Projected CO_2 savings in tonnes
- Average costs and benefits per dwelling
- Projected optimum technology mix for different development scenarios under each policy option

These results are presented in Section 4.

2.5 Consultation

The following organisations assisted with this research, through a formal consultation process:

1. Home Builders Federation.
2. NHBC
3. Construction Products Association
4. Oxford Environmental Change Institute
5. Energy Savings Trust
6. PassivHaus UK (c/o Building Research Establishment (BRE))
7. PassivHaus Institute (Germany)
8. Renewable Energy Association
9. Element Energy

Product manufacturers were also invited to contribute technical and commercial information.

Section 3: Summary of Policy Options Modelled

3.1 Overview

The results are based upon the analysis of five alternative policy options. Each policy option was modelled while optimising on capital cost only (ie the cost of installing the required technologies within the new housing developments), or on the basis of the combined effect of capital costs and the further costs and benefits expected to arise over the life time of the technologies. Therefore, a total of 10 policy interventions were considered. A further model, referred to herein as the 'reference case', estimates the performance of the projected new housing in the absence of any new policy.

The results of each intervention case are presented net of the reference case to identify the likely impact (costs and benefits) arising specifically from each policy option.

It should be noted that control on performance through Building Regulations is only one of the factors influencing the carbon emissions from new housing. Other influences include local authority planning requirements, grants and other aid for LZC technologies, trends in the global price of technology, etc. The extent to which these are considered as part of the reference case is described below.

3.2 Reference case

The basis of the reference case is described in Table 3.1.

The factors considered broadly relate to three key areas:

- **Central and Local Government Policy** – as relating to the energy and carbon performance for new housing
- **Commitments made by Government Agencies to achieve minimum performance standards** – ie English Partnerships and the Housing Corporation (to become the Homes and Communities Agency)
- **Attitude of house builders to ongoing costs and benefits**

Table 3.1: Reference case assumptions

Consideration	Reference case assumption
Central and Local Government Policy	
Building Regulations standards for energy efficiency	It was assumed that no further amendments would be made to Building Regulations in the absence of one of the policy options considered in this research.
Policy requirements for use of renewable energy (under PPS22)	Currently 44% of local planning authorities have a 'Merton rule' relating to use of renewable energy in either draft or adopted form. It was assumed that 44% of new housing will be required to achieve a minimum of 10% of energy supply from renewable sources from 2008. Housing in Small Scale developments (<10 units) is assumed to be exempt from this requirement.
Uptake of zero stamp duty for zero carbon housing policy	The Treasury announcement that housing achieving their definition of zero carbon will be eligible for zero stamp duty (up to a cap of £15,000 per property) until 2012 will provide an incentive to build zero carbon homes beyond that covered by the policy options considered in this research. Treasury estimates are that costs (ie lost stamp duty) will increase to £15m per year in 2011/12 although no estimate of overall cost is provided. It is assumed that costs will grow regularly by £3m per year from 2008. It was assumed that most developers would only build zero carbon homes in areas where the stamp duty rebate would be sufficient to cover/offset the cost of achieving the higher standard, ie where the rebate would be between £12k and £15k per home. On this basis, £3m of avoided stamp duty would equal between 200 and 250 homes per year and by 2012 the number of zero carbon homes built would be between 1000 and 1250. Therefore, even at its point of highest uptake the total number of homes built to a zero carbon standard would be less than 1% of the total housing completions in that year and that over the period for which the policy is in effect it will affect under 0.4% of total completions. As a result it has been decided not to include the impact of this policy within the reference case. This is not to say that the zero stamp duty initiative will not result in valuable industry wide learning about the most suitable technological approaches for achieving zero carbon status, only that it is unlikely to result in direct reductions in technology cost.

Table 3.1: Reference case assumptions *(continued)*

Consideration	**Reference case assumption**
Commitments by Government Agencies	
Commitments by English Partnerships and the Housing Corporation	Both English Partnerships and the Housing Corporation have committed to delivering homes that achieve Code for Sustainable Homes Level 3 (ie a 25% improvement on current Building Regulations). Social housing completions are estimated at 24,000 per annum with an estimated further 10,000 homes completed by English Partnerships. Going forward it is projected that around 20% (or 40,000 homes) will be constructed by the Homes and Communities Agency. Public sector commitments to achieve a 25% improvement on current part (as part of delivering Code level 3) prior to 2010 were not included in the reference case on the basis that they were inextricably linked the overall policy objective of helping deliver reduced carbon emissions through building regulations. English Partnerships is also committed to delivering some zero carbon homes under the Carbon Challenge initiative. As with stamp duty relief, however, the impact of the Carbon Challenge is not expected to directly influence technology costs, albeit that it will be valuable in helping the industry determine suitable technology options. It is, therefore, not considered in the reference case.
Attitude of house builders to ongoing costs and benefits	
	Over time, increased public awareness together with the potential involvement of ESCOs in large developments may influence the selection of solutions that are optimal for both capital and ongoing costs and benefits. At present, however, it is assumed that the majority of house builders would aim for lowest capital cost rather than lowest whole life cost when selecting renewable or energy efficiency measures. As a result the reference case is optimised on the basis of capital costs only.

3.3 Policy intervention options

The principles determining the basis of each policy intervention option are:

- the phasing of the implementation of the policy at key stages in 2010, 2013 and 2016
- the potential for the use of off-site renewable energy generation to offset the carbon emissions from proposed developments
- the presence of mandatory minimum levels of energy efficiency

Table 3.2 describes the different policy intervention cases considered.

Table 3.2: Intervention cases

Policy option	Improvement on Part L1a 2006			Optimisation based on
	2010	2013	2016	
1: Base case	25%	44%	Zero carbon (all carbon saving measures on-site, no mandatory energy efficiency level)	Capital cost
1a: Base case				Capital and ongoing costs and benefits
2: As Option 1 but missing out the interim (44%) step	25%	25%	Zero carbon (all carbon saving measures on-site, no mandatory energy efficiency level)	Capital cost
2a: As Option 1a but missing out the interim (44%) step				Capital and ongoing costs and benefits
3: Allowing off-site generation after 2016 without energy efficiency backstops	25%	44%	Zero carbon (some or all of the carbon reduction can be secured from off-site sources)	Capital cost
3a: Allowing off-site generation after 2016 without energy efficiency backstops				Capital and ongoing costs and benefits
4: Allowing off-site generation after 2016 with mandatory energy efficiency backstops	25%	44%	Zero carbon (some of the carbon reduction can be secured from off-site sources, but it is necessary to achieve EST Advanced Practice levels of energy efficiency)	Capital cost
4a: Allowing off-site generation after 2016 with mandatory energy efficiency backstops				Capital and ongoing costs and benefits
5: As base case but with mandatory energy efficiency backstops (equivalent to the requirements of level 6 in the Code for Sustainable Homes)	25%	44%	Zero carbon (it is necessary to achieve EST Advanced Practice levels of energy efficiency)	Capital cost
5a: As base case but with mandatory energy efficiency backstops (equivalent to the requirements of level 6 in the Code for Sustainable Homes)				Capital and ongoing costs and benefits

Section 4: Results

This section presents the model results for the reference case and each intervention case. In line with the requirements of the Treasury Green Book the following results are calculated for individual dwellings within each scenario, and for England and Wales as a whole:

- Benefits
  - Present value of ongoing benefits (£)
  - Carbon savings per year in 2025 and 2050[17], and in total from dwellings built between 2008 and 2025 (tonnes CO_2)
  - Value of carbon saved using the shadow price of carbon (£)
- Costs
  - Present value of capital costs (£)
  - Present value of contributions to off-site renewable energy generation (if applicable) (£)
  - Present value of ongoing costs (£)
- Net present value of costs and benefits excluding the value of carbon saved (£)
- Net present value of costs and benefits including the value of carbon saved (£)
- Carbon abatement cost, ie £ per tonne of carbon saved (undiscounted)
- Optimum technology mix

In line with Government guidance, all carbon savings are presented in an undiscounted form, ie one tonne of carbon saved in the future being equivalent to one tonne of carbon saved today.

4.1 Overall Results Summary

The costs and benefits associated with each policy option are shown in Figure 4.1 and Table 4.1. The percentage increase in construction costs is shown in Table 4.2. Appendix C contains more detailed results presented as averages for different dwelling types and development scenarios.

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[17] To estimate the annual carbon savings in 2050, it was assumed that housing building would continue at the same rate and standard as in 2025 through to 2050.

Figure 4.1: Summary of the net present cost of each policy option

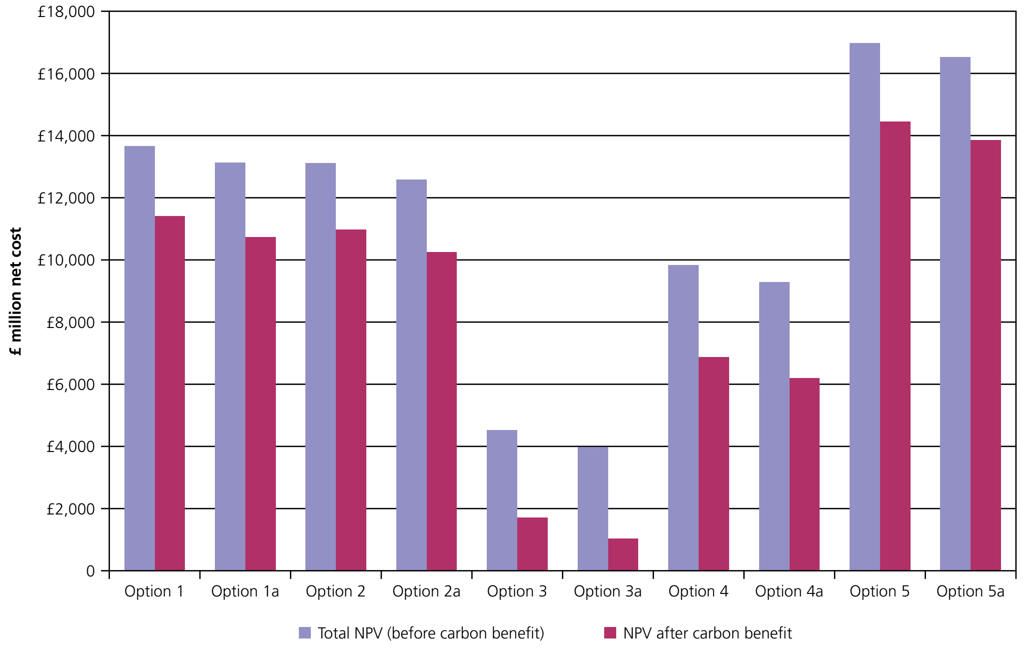


Table 4.1: Summary of overall results for different policy options (medium scenario)

Option	Total benefits (£) PV	Total costs (£) PV	Offset payments	Total NPV (before carbon benefit)	Carbon benefit (from homes built to 2025)	NPV after carbon benefit	Abatement cost	Abatement cost	Annual CO_2 savings by 2020 (undiscounted)
	£m	£m	£m	£m	£m	£m	£ per t of CO_2 (discounted)	£ per t of CO_2 (undiscounted)	million t
Option 1	£21,889	–£35,547	£0	**–£13,658**	£2,239	**–£11,420**	£213	£108	2.85
Option 1a	£23,429	–£36,568	£0	**–£13,139**	£2,407	**–£10,732**	£191	£97	3.15
Option 2	£20,767	–£33,877	£0	**–£13,110**	£2,130	**–£10,980**	£214	£109	2.62
Option 2a	£22,581	–£35,163	£0	**–£12,582**	£2,332	**–£10,250**	£188	£96	2.98
Option 3	£4,603	–£4,985	£4,145	**–£4,527**	£2,819	**–£1,707**	£60	£27	2.86
Option 3a	£6,650	–£6,639	£3,987	**–£3,977**	£2,939	**–£1,038**	£50	£23	3.16
Option 4	£8,898	–£15,342	£3,392	**–£9,836**	£2,957	**–£6,879**	£127	£56	2.86
Option 4a	£10,680	–£16,674	£3,293	**–£9,287**	£3,086	**–£6,201**	£114	£51	3.16
Option 5	£23,912	–£40,884	£0	**–£16,973**	£2,521	**–£14,452**	£246	£115	2.82
Option 5a	£25,252	–£41,776	£0	**–£16,523**	£2,667	**–£13,857**	£226	£107	3.12

Table 4.2: Increase in construction costs over 2006 Part L1a for different policy options (medium scenario)

Option	Increase in construction costs (over Part L) in 2011	Increase in construction costs (over Part L) in 2014	Increase in construction costs (over Part L) in 2017	% increase in construction costs (over Part L) in 2025
	%	%	%	%
Option 1	2.5%	5.0%	17.8%	14.3%
Option 1a	3.1%	5.8%	17.9%	14.4%
Option 2	2.5%	2.3%	17.9%	14.3%
Option 2a	3.1%	3.0%	17.9%	14.4%
Option 3	2.5%	5.0%	4.7%	4.6%
Option 3a	3.1%	5.8%	5.3%	5.1%
Option 4	2.5%	5.0%	12.7%	11.9%
Option 4a	3.1%	5.8%	13.3%	12.4%
Option 5	2.5%	5.0%	23.6%	17.7%
Option 5a	3.1%	5.8%	23.9%	17.7%

Table 4.1 presents the overall results for each policy option, comprising

- The net present value of each policy option, applied to the projections for new build housing in England over 2008 to 2025, taking into account the estimated value of both the costs and benefits arising. This is shown both before and after the application of the estimated benefit of the associated carbon reduction based upon the Shadow Price of Carbon
- The abatement cost for each policy option (ie the undiscounted cost of the CO_2 saved as a result of the policy shown); this effectively represents the comparative measure of the efficiency of each policy option
- Estimated annual CO_2 savings by 2020
- The estimated percentage increase in construction costs resulting from each policy option at the key step changes of 2010, 2013 and 2016, and also in 2025, the last year for which housing growth has been analysed in this research

These results indicate that:

- Net costs are highest for Options 5 and 5a, these options require all of the carbon reductions to be achieved on-site and there is a obligation for at least Advanced Practice levels of energy efficiency. After 2016, these options most closely resemble the standard required by level 6 of the Code for Sustainable

Homes. Costs are higher for these options because a) all carbon reduction must be achieved on-site; and, b) it is necessary to achieve high levels of thermal performance in each home, this has the effect of both increasing costs and reducing the carbon effectiveness of CHP systems (by reducing the overall heat demand of the homes and hence the potential to produce low carbon electricity).

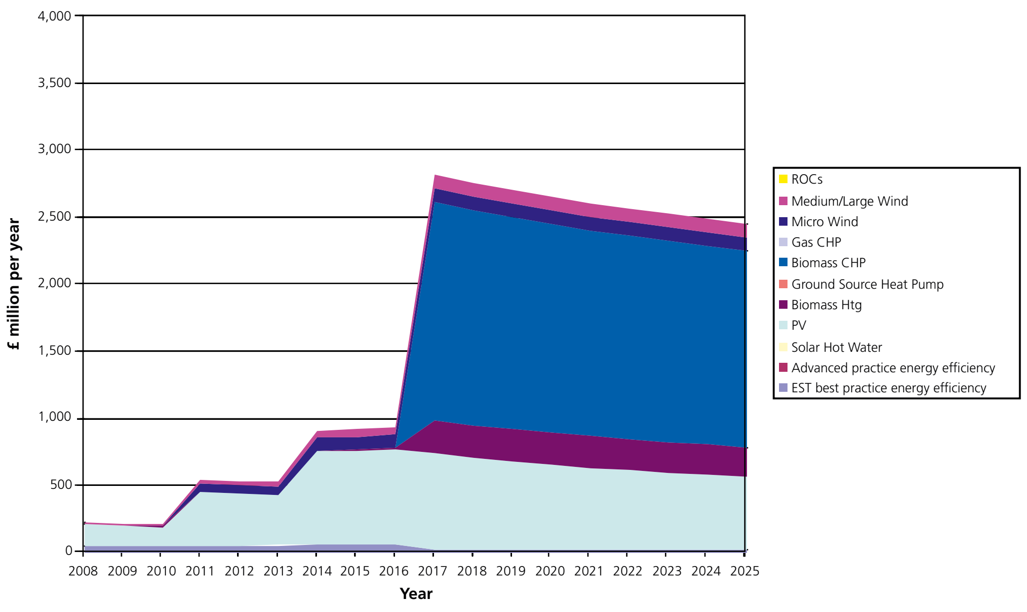
- After 2016 (ie once the zero carbon standard is in place), there is little or no impact on net costs between options optimised on capital cost only and those taking capital and ongoing costs into account. However, before 2016 net costs are lower where both capital and ongoing costs and benefits are taken into consideration. As a result the cumulative net costs by 2025 are lower for those options that include ongoing cost in the optimisation process than for those where only capital cost is considered.
- Policy Options 2 and 2a have slightly reduced net costs in comparison to Options 1 and 1a. This is because of the avoidance of the change in Building Regulations in 2013 (to a 44% improvement on the current position). Not surprisingly Options 2 and 2a also result in slightly lower overall carbon reductions than under Options 1 and 1a. The abatement cost (£ per tonne of carbon saved) are virtually identical for Options 1 and 2 and 1a and 2a indicating that while a tightening of regulations in 2013 reduces overall carbon emissions it does not increase the overall efficiency of the policy option by 2025.
- After 2016, Options 3(a) and 4(a) have substantially lower net costs than those options requiring all carbon savings to be achieved on-site. It should be noted however that Option 3(a) will have little or no impact on the quality of new housing after 2016 and that as a result no direct benefits will accrue to homeowners.
- The level of carbon benefit is reasonably consistent for each option at between £2.1 and £2.7 billion. Those options optimised on the basis of both capital and ongoing costs and benefits have greater overall carbon benefit (reflecting the value of the additional carbon savings achieved prior to 2017).

Results are not shown specifically for the reference case. However, all of the above figures are net of the reference case. The technologies predominating under the reference case are PV and EST Best standard energy efficiency improvements, together with medium/large scale wind (where applicable) on Market Town size developments and biomass communal heating on the larger schemes.

4.2 Option 1

Figure 4.2 illustrates the annual impact on development costs of policy Option 1 and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.2: Aggregate capital costs per annum apportioned against the dominant technology options; Option 1 (medium scenario)



The Base Case policy option assumes that in addition to 25% and 44% improvements on the current Part L1a of the Building Regulations in 2010 and 2013 respectively, all new housing will achieve zero carbon status from 2016 through on-site carbon saving measures. This policy option does not assume a requirement to achieve a mandatory level of energy efficiency prior to the use of renewable energy technologies.

The estimated total net present cost of this policy option is £13.6 billion, equating to an average cost premium of approximately £3,725 (or 4%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025.

The net present cost falls to £11.4 billion; or an average of £3,115 per dwelling after account is taken of the carbon benefit.

At each step change in policy, average construction costs are expected to increase, by a relatively modest 2.5% in 2011, 5.0% by 2014, and peaking at 17.8% for new dwellings constructed after 2016 when the full zero carbon requirement comes into effect. It is anticipated, however, that within 8 years of this last step change, the average cost premiums should fall back to 14.3% due to the benefits deriving from technology learning.

These annual average figures hide significant variation in the costs for different types of home and those built in different development type. Appendix C presents average costs split by building type and by development scenario. The costs are highest for dwellings built in smaller numbers and at lower densities, reflecting the limited scope for achieving the economies of scale associated with communal systems such as biomass CHP.

In general, all dwellings benefit from an overall net reduction in running costs, at each step change in policy. The exception is City Infill sites after 2016, where the predominant technology selected is biomass CHP which when applied to relatively few units, as is the case in this scenario, is believed to be more expensive to operate than a standard gas heating system.

One potential limitation to achieving full zero carbon status, however, is that the results show that City Infill developments would not be able to achieve zero carbon status with the technologies and design options considered in the study. All of the other development types modelled were able achieve zero carbon using on-site technologies. Analysis of the shortfall in carbon reductions arising on the City Infill sites showed that it is also possible to achieve zero carbon status for this scenario using on-site technologies, but that this would require careful redesign to increase the area of roof/exposed surface on which PV could be placed.

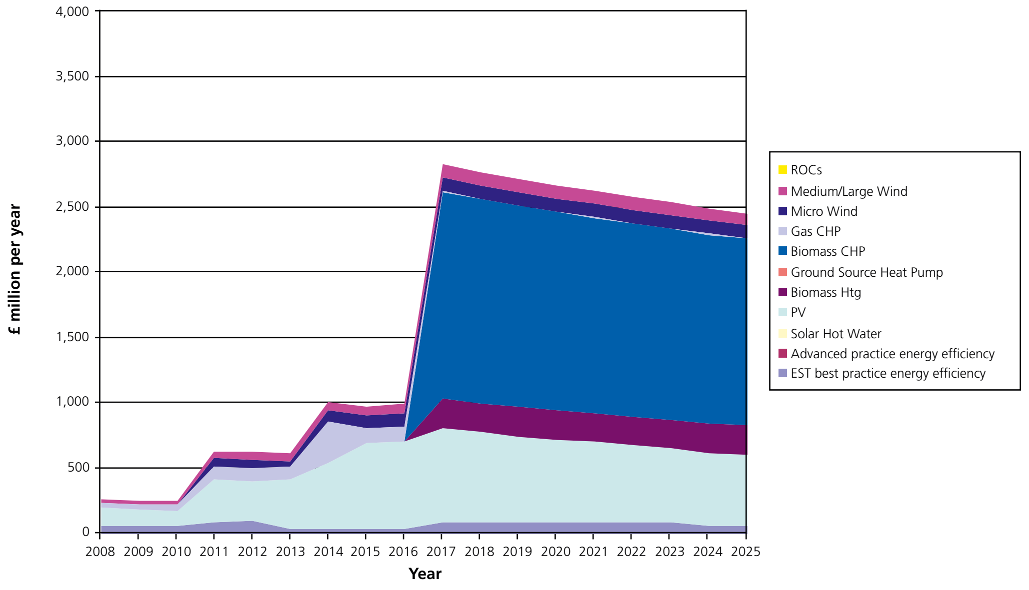
Prior to 2016, the overall technology mix shows a slight bias toward PV. After this date, biomass CHP and PV both come to the fore, along with large scale wind where this is deemed feasible. It is notable that under this policy option relatively little emphasis is placed on energy efficiency measures. This is at least partially a result of the predominance of biomass CHP, because when this technology is used greater quantities of low carbon electricity are generated when the base head load is higher (ie if the building is less thermally efficient).

By 2020 annual carbon savings from housing built since 2008 are estimated to be 2.85 million tonnes, under this policy option.

4.3 Option 1a

Figure 4.3 illustrates the annual impact on development costs of policy Option 1a and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.3: Aggregate capital costs per annum apportioned against the dominant technology options; Option 1a (medium scenario)



Option 1a is as the Base Case (Option 1) but with the technology options selected on the basis of overall net present value rather than capital cost only.

The estimated total net present cost of this policy option is £13.1 billion, equating to an average cost premium of approximately £3,590 (or 3.9%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025.

The net present cost falls to £10.7 billion or an average of £2,930 per dwelling after account is taken of the carbon benefit; an approximate 6% reduction against the comparable costs from the Base Case (Option 1).

Average construction costs at each change in policy are expected to be slightly higher than in comparison to the Base Case (Option 1), totalling 3.1% in 2011, 5.8% by 2014, and peaking at 17.9% for new dwellings constructed after 2016 when the full zero carbon requirement comes into effect.

It is anticipated, however, that within 8 years of this last change the average cost premiums should fall back to 14.4% due to the benefits deriving from learning rates.

The costs per dwelling follow a similar pattern in comparison to the Base Case (Option 1).

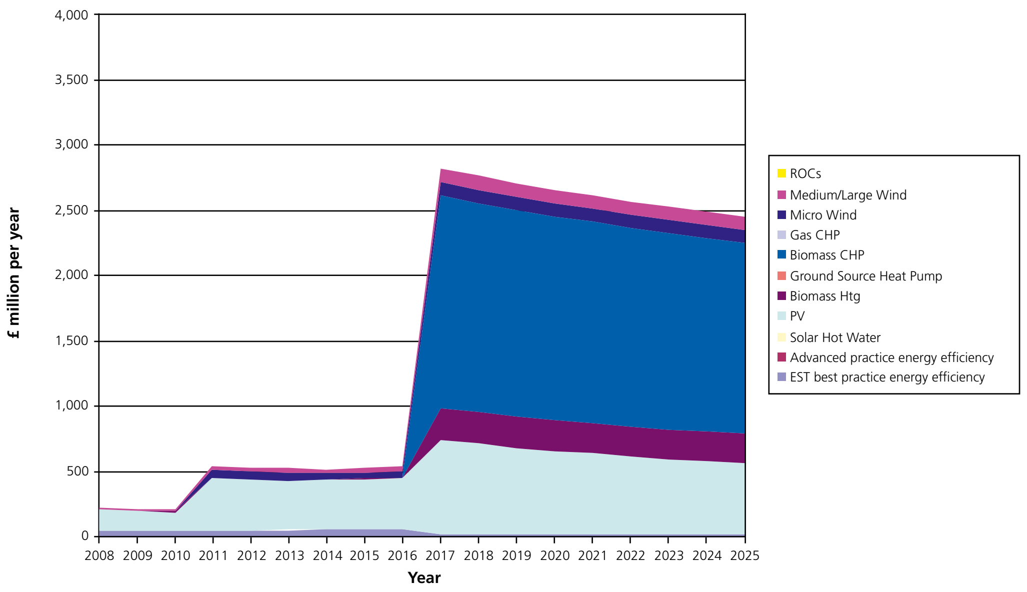
One notable change is in the mix of technologies selected prior to 2016. In this option wind (where applicable), PV, EST Best energy efficiency measures, and gas CHP on larger sites dominate. After 2016, the situation is very similar to Option 1 where biomass CHP and PV both come to the fore, along with large scale wind where deemed feasible. This illustrates the relatively low level of flexibility in design solutions for achieving zero carbon status.

By 2020 annual carbon savings from housing built since 2008 are estimated to be 3.15 million tonnes under this policy option.

4.4 Option 2

Figure 4.4 illustrates the annual impact on development costs of policy Option 2 and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.4: Aggregate capital costs per annum apportioned against the dominant technology options; Option 2 (medium scenario)



Option 2 is the same as the Base Case (Option 1), but with the removal of the incremental 44% improvement in carbon emissions reduction in 2013, thus maintaining policy at an improvement level of 25% against the Building Regulations up until 2016, after which all new housing will again have to achieve zero carbon status.

As with the Base Case (Option 1), this policy option does not assume a requirement to achieve a mandatory level of energy efficiency prior to the use of renewable energy technologies.

The estimated total net present cost of this policy option is £13.1 billion, equating to an average cost premium of approximately £3,580 (or 3.9%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025.

The net present cost falls to £11.0 billion, or an average of £2,995 per dwelling after account is taken of the carbon benefit. This is a 4% reduction against the comparable costs from the Base Case (Option 1), related directly to the omission of the requirement to achieve the 44% standard between 2013 and 2016.

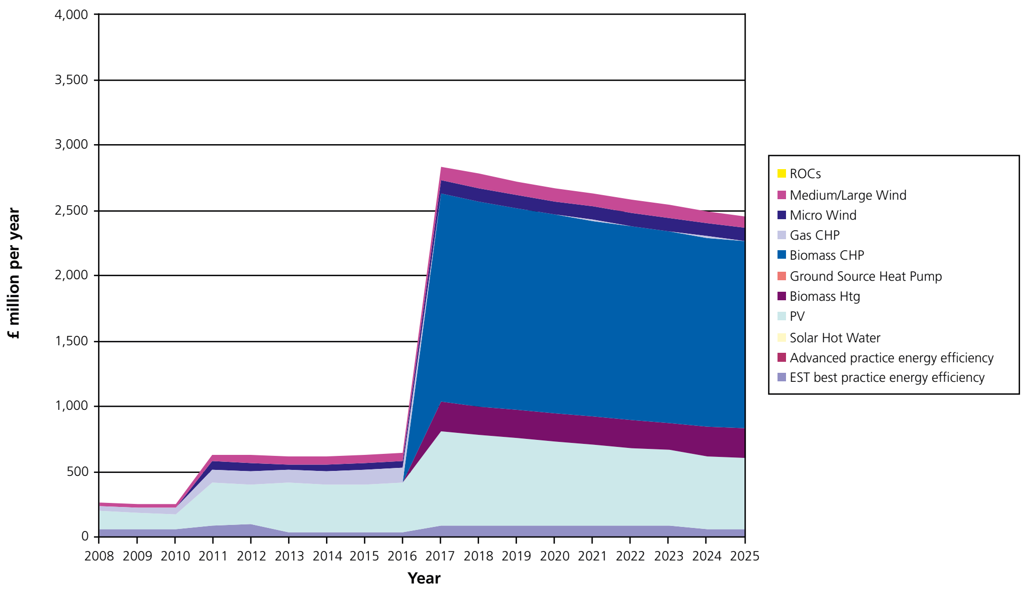
This is also reflected in the construction cost increases at each change, which are as the Base Case (Option 1) other than in 2014, where the cost premium is reduced to 2.3% from 5.0%. This reflects both the reduced standard and the benefits deriving from learning rates from 2010.

The effect on technology mix is that PV, wind and EST Best energy efficiency measures are likely to predominate until 2016. The technology mix profile is consistent with the Base Case (Option 1).

4.5 Option 2a

Figure 4.5 illustrates the annual impact on development costs of policy Option 2a and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.5: Aggregate capital costs per annum apportioned against the dominant technology options; Option 2a (medium scenario)



Option 2a is as Option 2 but with the technology options selected on the basis of overall net present value rather than capital cost only.

The estimated total net present cost of this policy option is £12.6 billion, equating to an average cost premium of approximately £3,430 (or 3.7%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025.

The net present cost falls to £10.3 billion; or £2,795 per dwelling after account is taken of the carbon benefit; a 10% reduction against the comparable costs from the Base Case (Option 1).

The summary of construction cost increases at each change is broadly as Option 1a other than in 2014, where the cost premium is reduced to 3.1% from 5.8%. This reflects both the reduced standard and the benefits deriving from learning rates from 2010.

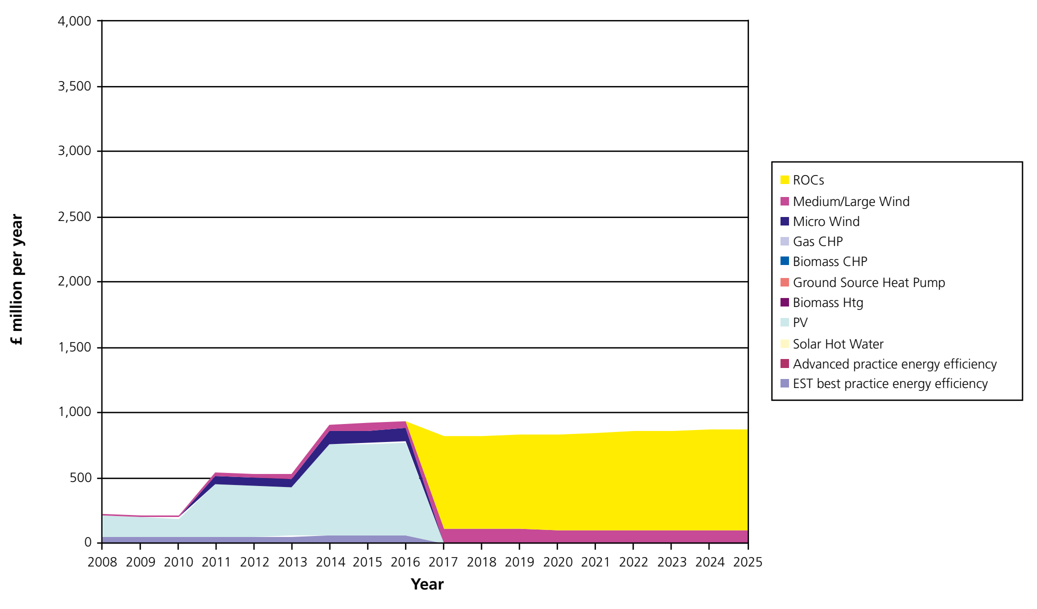
The effect on technology mix is that wind (where applicable), PV, EST Best energy efficiency measures, and gas CHP on larger sites, are likely to predominate until 2016. Again the technology mix profile is consistent with that for Option 1a.

By 2020 annual carbon savings from housing built since 2008 are estimated to be 2.98 million tonnes under this policy option.

4.6 Option 3

Figure 4.6 illustrates the annual impact on development costs of policy Option 3 and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.6: Aggregate capital costs per annum apportioned against the dominant technology options; Option 3 (medium scenario)



Option 3 assumes that 25% and 44% improvements will be required against the current Part L1a of the Building Regulations in 2010 and 2013 respectively, and that all new housing will achieve zero carbon status from 2016. This option differs from the Base case (Option 1), however, in that it would permit off-site measures to be considered from 2016, without a mandatory level of energy efficiency prior to doing this.

The ability to use off-site sources of renewable energy has a significant impact on the results in comparison to the previous options. The estimated total net present cost of this policy option is £4.5 billion, including payments for off-site renewables. This equates to an average net cost premium of approximately £1,235 (or 1.3%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025.

The net present cost falls to £1.7 billion after account is taken of the carbon benefit.

The primary reason for the lower net costs of this option is that ROCs (a proxy for contribution to off-site technologies) are selected almost exclusively as the most cost effective approach to meeting the zero carbon target at 2016, supplemented only by the use of large wind where deemed feasible.

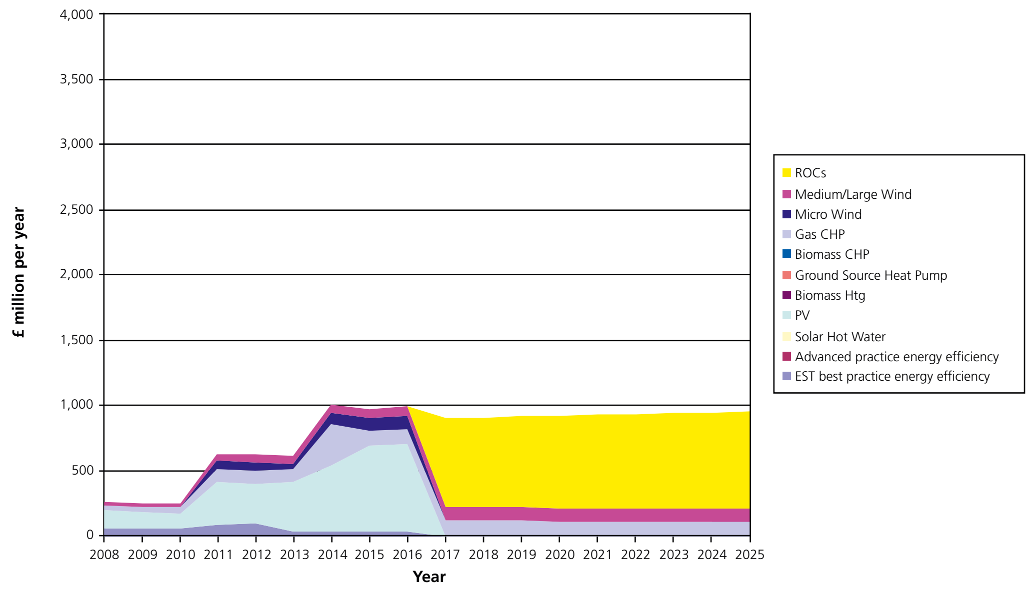
Under this option the percentage increase in construction cost shows increases of 2.5% in 2011 and 5.0% by 2014, in line with earlier options, but the figures only increase 4.7% after 2016 as all of the investment in on-site carbon saving is diverted into contributions towards off-site renewables. This relatively extreme option demonstrates that, without mandatory backstops, an unconstrained permit to use off-site contributions to meet the zero carbon target is unlikely to result in any appreciable housing performance improvement over the current Building Regulations.

The calculation of annual carbon savings by 2020 is comparable (slightly higher) to that of earlier options at 2.86 million tonnes. However, this clearly is not being achieved through on-site measures. Furthermore, there is no reduction in homeowner energy costs after 2016, with the exception of the 20% of Market Town sites assumed to have access to large scale wind on-site (or via local private wire).

4.7 Option 3a

Figure 4.7 illustrates the annual impact on development costs of policy Option 3a and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.7: Aggregate capital costs per annum apportioned against the dominant technology options; Option 3a (medium scenario)



Option 3a is as the Option 3 but with the technology options selected on the basis of overall net present value rather than capital cost only.

Up until 2016, the results here follow the same trend as the earlier NPV optimised models, Options 1a and 2a.

The estimated total net present cost of this policy option is £4.0 billion, equating to an average cost premium of approximately £1,085 (or 1.1%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025.

The net present cost falls to £1.0 billion after account is taken of the carbon benefit; a 40% reduction against the cost of Option 3, and a 90% reduction against the comparable costs from the Base Case (Option 1).

Following a similar pattern to Option 3, the construction cost figures show increases of 3.1% in 2011, 5.8% in 2014 and 5.3% in 2017. The slightly higher capital cost after 2016 is a result of the continued presence of gas CHP systems in the technology mix (favoured because of their superior overall performance in comparison to offsetting).

The technology mixes are broadly consistent with the other NPV optimised options up to 2016 with wind (where applicable), PV, EST Best energy efficiency measures, and gas CHP on larger sites, predominating.

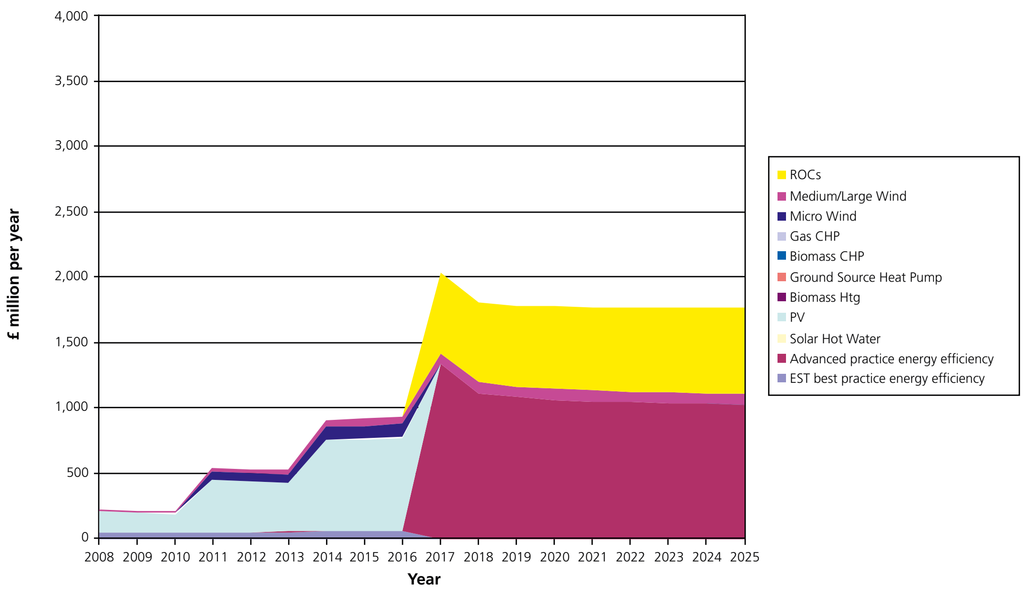
After 2016, ROCs again dominate as a carbon reduction method (together with large wind) but the inclusion of gas CHP on the larger sites is an interesting development. Gas CHP is more cost effective in whole life terms than the use of off-site renewables (for which no lifecycle benefits arise) and continues to be delivered under Option 3a (and later 4a). The Gas CHP is a feasible technology even though it is not zero carbon because the carbon emissions generated by the use of natural gas can be fully offset using low cost off-site renewables. Where this is not the case, eg Options 1a, 2a and 5a, gas CHP does not feature in the technology mix after 2016.

Annual carbon savings are broadly as Option 3.

4.8 Option 4

Figure 4.8 illustrates the annual impact on development costs of policy Option 4 and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.8: Aggregate capital costs per annum apportioned against the dominant technology options; Option 4 (medium scenario)



Option 4 addresses a key limitation of Option 3 by introducing a mandatory backstop of EST Advanced practice energy efficiency measures be adopted prior to selecting an off-site solution to achieve zero carbon after 2016. In all other respects, this option is as Option 3.

The estimated total net present cost of this policy option is £9.8 billion, including payments for off-site. This equates to an average cost premium of approximately £2,680 (or 3%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025. The net present cost falls to £6,879m after account is taken of the carbon benefit.

The primary reason for the increased costs compared to Option 3 is that, whilst in the years prior to 2016 the technology selection is broadly the same, after 2016 the use of off-site payments is tempered by an obligation to introduce EST Advanced Practice measures. This policy option represents the first large scale use of the EST Advanced Practice standard as a carbon reduction measure (and only because it is a mandatory requirement).

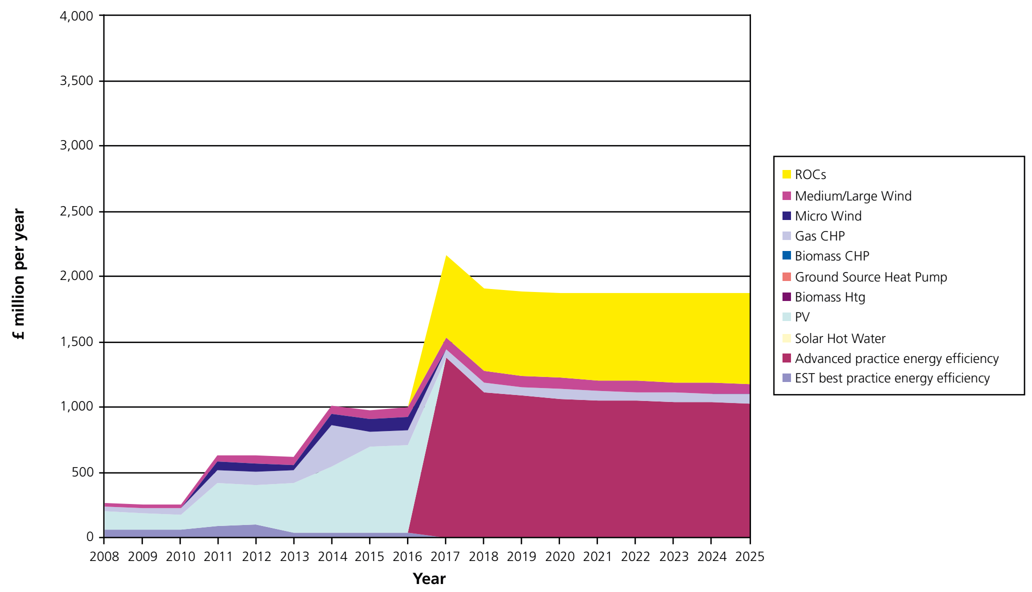
This can also be seen in the construction cost figures, which show increases of 2.5% in 2011 and 5.0% by 2014, in line with Option 3, but increasing slightly to 12.7% at 2016.

The calculation of annual carbon savings by 2020 is comparable to that of the earlier options at 2.86 million tonnes. Unlike Option 3 there is an ongoing improvement in the performance standard of new housing constructed after 2016. However, the costs of achieving this standard are high relative to the other potential carbon reduction methods.

4.9 Option 4a

Figure 4.9 illustrates the annual impact on development costs of policy Option 4a and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.9: Aggregate capital costs per annum apportioned against the dominant technology options; Option 4a (medium scenario)



Option 4a is as the Option 4 but with the technology options selected on the basis of overall net present value rather than capital cost only. The results here follow the same trend as the earlier NPV optimised models, Options 1a and 2a and 3a.

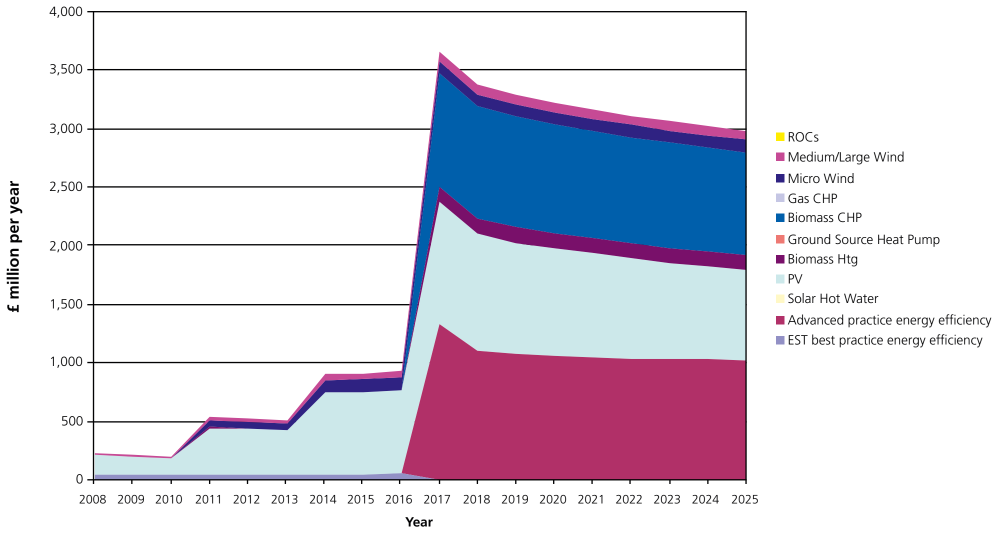
The estimated total net present cost of this policy option is £9.3 billion, equating to an average cost premium of approximately £2,530 (or 2.7%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025. The net present cost falls to £6.2 billion after account is taken of the carbon benefit.

As with earlier options, the estimated construction cost after 2010, 2013 and 2016 are broadly consistent with Option 4, if slightly higher (a result of the use of gas CHP with its higher capex but superior ongoing benefits). Annual carbon savings are also similar to Option 4.

4.10 Option 5

Figure 4.10 illustrates the annual impact on development costs of policy Option 5 and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.10: Aggregate capital costs per annum apportioned against the dominant technology options; Option 5 (medium scenario)



This option most closely correlates to the definition of Level 6 of the Code for Sustainable Homes. As such it represents an interesting comparison with the Base Case set in this research.

The estimated total net present cost of this policy option is £17.0 billion. This equates to an average cost premium of approximately £4,630 (or 5%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025.

The net present cost falls to £14.5 billion; or an average of £3,940 per dwelling after account is taken of the Carbon Benefit.

This is the most expensive of the Options considered, and the net cost is 27% higher than the Base Case (Option 1). This can also be seen in the construction cost figures, which show increases of 2.5% in 2011 and 5.0% by 2014, in line with Option 1, but increasing to a peak of 23.6% in 2017, before dropping back to 17.7% by 2025.

The primary reason for the increased costs is that, whilst in the years prior to 2016 the technology selection is broadly as Option 1, after 2016 the use of EST Advanced Practice measures are mandatory adding to development costs whilst simultaneously reducing the potential for carbon reductions through biomass CHP systems (because of the reduced heating load in these homes). This option (together with Option 5a) does deliver the greatest real reductions in energy consumption and largest improvements in building envelop performance, if not greater carbon savings.

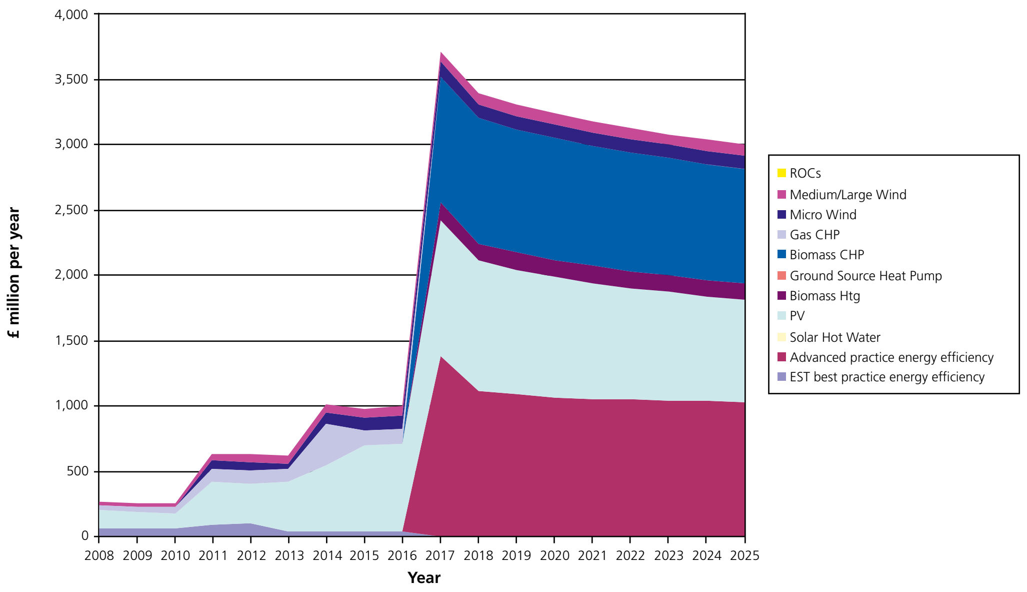
It is noticeable that where EST Advanced Practice performance is utilised on a large scale (eg where it is a mandatory requirement) the cost of complying with the zero carbon standard falls more rapidly than under other options. This is because of the relatively low current uptake of the EST Advanced Practice standard and the significant impact that constructing circa 240,000 houses a year to this standard would have on its cost.

The calculation of annual carbon savings by 2020 is comparable to that of Option 1, at 2.82 million tonnes.

4.11 Option 5a

Figure 4.11 illustrates the annual impact on development costs of policy Option 5a and the mix of technologies used to achieve the required performance standard in each year.

Figure 4.11: Aggregate capital costs per annum apportioned against the dominant technology options; Option 5a (medium scenario)



Option 5a is the same as Option 5 but with the technology options selected on the basis of overall net present value rather than capital cost only.

Prior to 2017, the results here follow the same trend as the earlier models that are optimised on capital and ongoing costs and benefits, ie Options 1a and 2a, 3a and 4a. Thereafter they are consistent with Option 5.

It can be seen that the estimated total net present cost of this policy option is £16.5 billion, equating to an average cost premium of approximately £4,510 (or 4.8%) per dwelling across all of the new dwellings projected to be constructed between 2008 and 2025.

The net present cost falls to £13.9 billion; or £3,780 per dwelling after account is taken of the carbon benefit.

The construction cost figures are broadly consistent with Option 5, as are annual carbon savings.

4.12 Estimation of carbon savings by 2050

Assuming that the low/zero carbon performance of each dwelling is maintained after the end of life of the initial technology then the different options perform in a similar manner. Before the move to zero carbon, greater carbon reductions are seen where the policy options includes optimisation on both capital and ongoing costs. However, after 2016 there is very little difference in carbon saving between any option and as a result the total difference in carbon reduction by 2050 is minor.

Whichever policy alternative is ultimately taken forward, the amount of CO_2 saved per annum by 2020 is broadly consistent, ranging between 2.62 Mt to 3.16 Mt. Further, by 2050, the dwellings built up to 2025 will save an estimated 6.2 Mt per annum or 195 Mt in total[18]. If construction rates continued at 2025 levels through to 2050 then the carbon saving achieved in comparison to current practice could be 21.5 Mt per annum in 2050 or 392 Mt in total.

4.13 Sensitivity Analysis

To test the sensitivity of the key input data assumptions used in the study, three scenarios were modelled within each run based upon low, medium (Base Case) and high figures.

The complexity of the modelling process precludes full probabilistic analysis using these variables. The three scenarios reflect 'best', 'central' and 'worst' case assumptions, thereby providing upper and lower bounds to the cost and benefit analysis.

The scenarios were initially run on the basis of the following assumptions:

- Capital cost: sensitivity scenarios based upon a variance of +/- 10% from the medium cost, whereby the High scenario is 10% greater than Medium and the Low scenario is 10% lower than Medium. The variance of +/- 10% is representative of the level of accuracy typically expected within the construction industry from preliminary cost modelling techniques similar to those used in this research
- Ongoing costs: sensitivity scenarios also based upon a variance of +/- 10% from the medium cost, whereby the High scenario is 10% greater than Medium (in other words, the prospective overall reduction when benefits is taken into account is 10% lower than Medium) and the Low scenario is 10% lower than Medium (with the result that the prospective overall reduction when benefits is taken into account is 10% greater than Medium)
- Learning rates: the variance between the High, Medium and Low scenarios varies each technology option. The figures used are presented in Table 2.14
- Shadow price of carbon: in the Low scenario the shadow price of carbon is taken at a rate equivalent to 50% of the Medium scenario value. In the High scenario the rate used is double that of the Medium scenario value

All other input data remained at a constant rate throughout the sensitivity modelling.

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[18] Assuming that they maintain their zero carbon status in perpetuity.

Further sensitivity analysis was carried out to investigate the impact of future energy price scenarios on the results. Projected price change profiles were developed for the high and low scenarios derived from Communities and Local Government indicative data on average prices of domestic fuel for the period 2006 to 2020. These figures represent assumptions only for the purposes of sensitivity analysis and should not be deemed to represent considered forecasts for energy price changes. Table 4.2 shows the annual percentage changes used assuming that energy prices remain constant under the medium scenario.

Table 4.2: Energy price changes represented as percentage change against base price used in sensitivity analysis

Year	Gas (High)	Gas (Low)	Electricity (High)	Electricity (Low)
2008	10%	–15%	2%	–7%
2009	11%	–21%	4%	–11%
2010	12%	–28%	5%	–14%
2011	14%	–34%	5%	–14%
2012	15%	–40%	4%	–14%
2013	16%	–47%	4%	–14%
2014	18%	–53%	4%	–14%
2015	19%	–59%	4%	–14%
2016	20%	–58%	4%	–14%
2017	21%	–57%	4%	–14%
2018	23%	–55%	4%	–14%
2019	24%	–54%	4%	–14%
2020	25%	–53%	4%	–15%
Beyond 2020	25%	–53%	4%	–15%

Source: Communities and Local Government, 2007

Finally, a further model was run to consider the impact of not permitting the use of micro wind.

4.13.1 Sensitivity to costs, carbon price and learning rates

Table 4.3 shows the overall results for the Base Case (Option 1) based upon High, Medium and Low scenarios with Table 4.4 presenting the percentage increase in construction cost over current building Regulations. These results are summarised graphically in Figure 4.12.

Figure 4.12: Net present cost of high, medium and low scenarios for Option 1

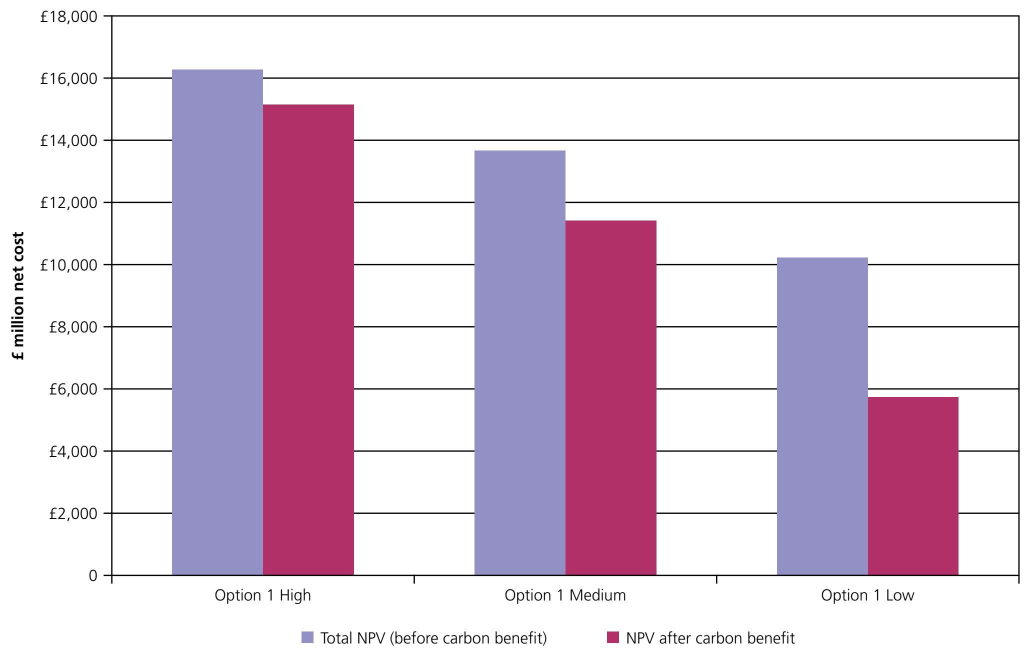


Table 4.3: Summary of overall results for policy Option 1 (High, Base case and Low scenarios – No change to energy projections)

	Total benefits (£) PV	Total costs (£) PV	Offset payments	Total NPV (before carbon benefit)	Carbon benefit (from homes built to 2025)	NPV after carbon benefit	Abatement cost	Abatement cost	Cumulative (undiscounted) CO_2 savings by 2065	Annual CO_2 savings by 2020 (undiscounted)	Annual CO_2 savings by 2050 (undiscounted) assuming build at current rates through to 2050
Option	**£m**	**£m**	**£m**	**£m**	**£m**	**£m**	**£ per t of CO_2 (discounted)**	**£ per t of CO_2 (undiscounted)**	**million t**	**million t**	**million t**
Option 1 High	£21,896	–£38,167	£0	**–£16,272**	£1,120	**–£15,152**	£253	£129	126	2.85	14.78
Option 1 Base Case	£21,889	–£35,547	£0	**–£13,658**	£2,239	**–£11,420**	£213	£108	126	2.85	14.78
Option 1 Low	£21,826	–£32,049	£0	**–£10,222**	£4,482	**–£5,741**	£159	£81	126	2.85	14.79

Table 4.4: Increase in construction costs over 2006 Part L1a for policy Option 1 (High, Base case and Low scenarios – No change to energy projections)

	Increase in construction costs (over Part L) in 2011	Increase in construction costs (over Part L) in 2014	Increase in construction costs (over Part L) in 2017	% increase in construction costs (over Part L) in 2025
Option	**%**	**%**	**%**	**%**
Option 1 High	2.8%	5.8%	20.0%	16.3%
Option 1 Base Case	2.5%	5.0%	17.8%	14.3%
Option 1 Low	2.0%	3.9%	14.9%	11.6%

The first point to note is the wide range of cost for the overall net present value for the policy option based upon the variances considered. The medium (Base Case) assessment of £11.4 billion, after taking account of carbon benefit, could increase to a net present value of £15.2 billion under a worst case scenario; an increase of over 32%. Conversely, under the best case scenario the net present cost of the policy could be around half that of the medium assessment, at £5.7 billion (See Table 4.3).

This is primarily the result of the potential variance in costs although the increased carbon benefit for the best case scenario is also significant. From the table it can be seen that the benefits are broadly consistent across the three scenarios. This primarily results from the use of consistent fuel pricing across each scenario.

The analysis suggests that even in the worst case, construction costs should peak at 20.0% over the current Building Regulations Part L1a, against a Medium estimate of 17.8%, and could be as low as 14.9%.

The results for the other models follow a similar pattern to this and so have not been repeated here.

4.13.2 Impact of the non-availability of micro wind

It can be seen from the Tables 4.5 and 4.6 that, in overall cost terms, a model scenario which excludes the use of micro wind, has only a marginal effect. The impact is primarily seen in the technology mix in respect of small developments. A greater emphasis is likely to be placed on PV to achieve Level 3 compliance. After 2013, biomass communal heating also becomes a more dominant solution. It is also important to note, that without recourse to micro wind, the model shows that it would be possible to achieve zero carbon on small developments without reliance on off-site carbon reductions.

Table 4.5: Summary of overall results for policy Option 1 (medium: without micro wind)

	Total benefits (£) PV	Total costs (£) PV	Offset payments	Total NPV (before carbon benefit)	Carbon benefit (from homes built to 2025)	NPV after carbon benefit	Abatement cost	Abatement cost	Cumulative (undiscounted) CO_2 savings by 2065	Annual CO_2 savings by 2020 (undiscounted)	Annual CO_2 savings by 2050 (undiscounted) assuming build at current rates through to 2050
Option	**£m**	**£m**	**£m**	**£m**	**£m**	**£m**	**£ per t of CO_2 (discounted)**	**£ per t of CO_2 (undiscounted)**	**million t**	**million t**	**million t**
Option 1 Medium	£21,845	–£35,584	£0	**–£13,739**	£2,243	**–£11,496**	£215	£108	127	2.78	14.50

Table 4.6: Increase in construction costs over 2006 Part L1a for policy Option 1 (medium: without micro wind)

	Increase in construction costs (over Part L) in 2011	Increase in construction costs (over Part L) in 2014	Increase in construction costs (over Part L) in 2017	% increase in construction costs (over Part L) in 2025
Option	**%**	**%**	**%**	**%**
Option 1 Medium	2.6%	5.2%	17.9%	14.2%

4.13.3 Energy price sensitivity

Running the Option 1 Base Case model using the energy cost projections noted in Table 4.2 above, produced the results shown in Tables 4.7 and 4.8. In each scenario the cost of biomass was kept constant.

Total capital costs were the same for each scenario. Total benefits ranged from £16,630 (Low fuel projections) to £23,779 (high fuel projections), a deviation of +9% to –30% against the Base Case results. This resulted in the total NPV for the two scenarios as follows:

High energy projections:	£9.5 billion	(16.5% less than Base Case)
Low energy projections:	£14.8 billion	(29% higher than Base Case)

These results confirm that the higher energy prices are projected to rise, the greater the benefit and hence the lower the net overall cost when compared to the Base Case. The converse is true with falling energy projections.

Table 4.7: Summary of overall results for policy Option 1 (high energy and low energy projections)

	Total benefits (£) PV	Total costs (£) PV	Offset payments	Total NPV (before carbon benefit)	Carbon benefit (from homes built to 2025)	NPV after carbon benefit	Abatement cost	Abatement cost	Cumulative (undiscounted) CO_2 savings by 2065	Annual CO_2 savings by 2020 (undiscounted)	Annual CO_2 savings by 2050 (undiscounted) assuming build at current rates through to 2050
Option	**£m**	**£m**	**£m**	**£m**	**£m**	**£m**	**£ per t of CO_2 (discounted)**	**£ per t of CO_2 (undiscounted)**	**million t**	**million t**	**million t**
Option 1 High	£23,779	–£35,547	£0	**–£11,769**	£2,239	**–£9,530**	£183	£93	126	2.85	14.78
Option 1: Base case	£21,889	–£35,547	£0	**–£13,658**	£2,239	**–£11,420**	£213	£108	126	2.85	14.78
Option 1 Low	£16,630	–£35,547	£0	**–£18,918**	£4,135	**–£14,782**	£198	£69	273	2.85	22.79

Table 4.8: Increase in construction costs over 2006 Part L1a for policy Option 1 (high energy and low energy projections)

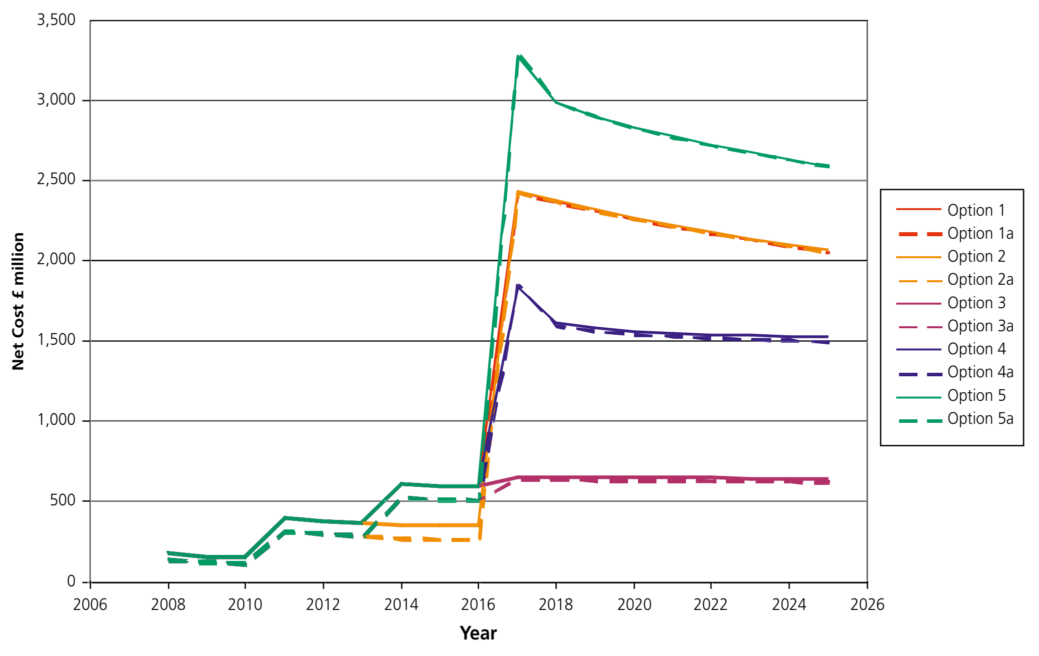
	Increase in construction costs (over Part L) in 2011	Increase in construction costs (over Part L) in 2014	Increase in construction costs (over Part L) in 2017	% increase in construction costs (over Part L) in 2025
Option	**%**	**%**	**%**	**%**
Option 1 High	2.5%	5.0%	17.8%	14.3%
Option 1: Base case	2.5%	5.0%	17.8%	14.3%
Option 1 Low	2.5%	5.0%	17.8%	14.3%

Section 5: Analysis

5.1 Financial costs and benefits

The financial costs and benefits are analysed primarily in terms of the relative net present costs of each option as shown in Figure 5.1.

Figure 5.1: Comparative net present cost of each Policy Option (medium scenario) to 2025



It is notable that, prior to 2016, the costs for all of the options fall within a relatively close range, but that the long term cost implications of alternative approaches to delivering zero carbon is substantial.

Options 5 and 5a are the most expensive, as these set the most challenging constraints for achieving zero carbon after 2016. Not surprisingly, the lowest overall cost options are 3/3a followed by 4/4a, which allow the unconstrained use of off-site contributions to achieve zero carbon after 2016. After 2016 the approaches set out under options 3/3a are divorced from any direct linkage to housing performance and, therefore, whilst this a more economically efficient means of delivering carbon reductions, it is effectively a form of a developer renewables obligation and avoids any impact on the housing product or householder. It should be noted, however, that Option 3/3a will have little or no impact on the quality of new housing after 2016 and that, as a result, no direct benefits will accrue to homeowners.

The results for Options 1/1a and 2/2a are very similar, reflecting the relatively similar overall regulatory obligations. The primary difference between the options 1/1a and 2/2a is that in Options 2/2a the 44% improvement change is omitted, thereby reducing the costs for years 2011 to 2013.

For each of the options 1/1a, 2/2a and 3/3a, the total net present costs for the NPV optimised options is slightly lower than the respective capital cost optimised options. This shows that, in cases where technology selection can be made on a long term financial basis, without any external influences, the long term financial benefits of the best performing technologies should outweigh any increase in initial capital cost over the lifetime of the asset. There is, therefore, an incentive (certainly up until 2016) for homeowners to be aware of the relative short and long term merits of different approaches to carbon reduction and that housebuilders are incentivised to pursue those approaches that give best whole life performance. Post 2016, the range of viable solutions to achieving zero carbon status is such that there is no difference between the approaches selected on capital cost or where a longer term view is taken.

The abatement cost, identified in Table 4.1, measures the overall cost of each policy option per tonne of CO_2 saved. It represents a concise indicator as to the overall value of each policy option. Not surprisingly, this measure follows the trend described above.

Those policy options, permitting off-site renewable energy generation, achieve a significantly lower abatement cost. It should be noted, however, that these options also provide less potential for savings in household energy bills as the carbon reductions (together with any associated benefits and risks) are delivered by a third party. Domestic energy costs are considered further below.

The extent to which zero carbon status could be maintained in perpetuity depends on whether sufficient financial savings can be accrued[19] over the life of a technology to pay for its eventual replacement. This is discussed later in this report.

5.1.1 Impact on domestic energy costs

For Options 1/1a, and 2/2a, the savings in energy cost could be up to £90 after 2010 and as much as £350 after 2016. In virtually all cases (see following) these savings are sufficient to deliver an overall saving in running costs over the life time of the asset once operational costs are taken into account. The results indicate that City Infill developments may be an exception to this, with a net increase in operational costs after 2016. This arises from the slight increase in maintenance

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[19] And critically whether in practice a portion of the financial savings would actually be saved to pay for replacement. It could be expected that an ESCO would take this approach but that a typical home owner would be unlikely to make provision for technology replacement throughout its active life.

costs associated with the biomass CHP system and the relatively low level of efficiency at which small scale systems currently operate (ie with a far poorer heat to power ratio than larger scale systems). This indicates that, at present, it may not be possible to achieve zero carbon on small City Infill developments without the use of off-site measures. It should be remembered, however, that such developments are expected to comprise a relatively minimal proportion of total annual new build projections and that technological developments in the CHP sector are progressing at a rapid pace with technologies being deployed at progressively smaller scales.

As would be expected, similar results are seen in Options 5 and 5a, indeed, with a potential for slightly increased fuel savings after 2016 due to obligation to use Advanced Practice energy efficiency measures.

The situation changes for those options permitting off-site contributions, ie Options 3/3a and 4/4a. Here, the results indicate that either fuel savings or, indeed, overall operational cost reductions are only likely to be seen on projects of suitable size or location whereby the cost of large scale on-site renewable systems may compete with the relatively low cost of off-site contributions. For instance, Market Town developments or Urban Regeneration schemes where large wind or gas CHP can be economically used. Even with the inclusion of a mandatory energy efficiency backstop, as in the case of Options 4/4a, however, the annual energy cost savings are seen to peak at £190 per annum, and in many cases are likely to be much less.

The average change in dwelling energy cost resulting from different policy options are identified in the tables included in Appendix C, together with the average overall change in operational costs for individual dwellings on a net present value basis.

5.2 Environmental benefits

5.2.1 Carbon Emissions

The underling rationale of each policy option is to address the carbon emissions from new housing. By 2020, the annual undiscounted quantity of CO_2 being saved from each scenario ranges between 2.62 million tonnes to 3.16 million tonnes. Further, by 2050, the dwellings built up to 2025 will save an estimated 6.2 Mt per annum or 195 Mt in total[20]. If construction rates continued at 2025 levels through to 2050 then the carbon saving achieved in comparison to current practice could be 21.5 Mt per annum in 2050 or 392 Mt in total.

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[20] Assuming that they maintain their zero carbon status in perpetuity.

The results indicate that, on the basis of the stated assumptions, the estimated carbon savings to 2050 follow a similar trajectory whether off site renewable technologies are permitted or not. On a more qualitative basis, however, it may be argued that improved housing quality is maximised where there is a backstop requirement for an advanced standard of energy efficiency to be built into each dwelling. This is also the option likely to actually lower energy use. Options 4/4a and 5/5a incorporate a backstop of EST Advanced practice standard.

5.3 Potential percentage of renewable energy generated by the proposed policy

Annex B of the DTI document *Meeting the Energy Challenge – A White Paper on Energy,* May 2007 estimates that by 2020 UK energy generation could total 367 TWh based upon Central policy estimates, of which 57TWh should be generated from renewable sources. From the modelling, it is estimated that, by 2020 the total of electrical energy being generated by renewable technologies which generate electricity (ie PV, Wind and biomass CHP) as a direct consequence of the policy could total 5.2 TWh; equivalent to approximately 1.4% of the total UK electrical energy projection.

5.4 Embodied energy of low carbon technologies

Carbon emissions in the context of the proposed revisions to Building Regulations relate to carbon emissions from operational energy. It is, however, recognised that the measures used to achieve operational carbon reductions, such as increased fabric insulation and the addition of renewable energy generating technologies, will add to the overall carbon embodied in the material content of buildings. A literature review of the carbon embodied within the technologies considered in this report was undertaken to assess whether there was any risk that any proposed policy would be self defeating (ie that it would lead to a building producing more carbon emissions during construction than would be saved from reduced operational energy consumption during the building's lifetime).

This review examined the proportion of embodied carbon within a number of building integrated renewable energy technologies, as well as additional embodied carbon incurred through improved building fabric, and tried to relate this to the operational carbon savings that might be achieved through the use of these technologies/measures over time.

The literature review showed that the depth of information and range of results available varied significantly for the different technologies. The discrepancy in results was affected by variables such as the manufacturing processes or the type of fuel used. In many cases, the literature gave data on embodied energy, rather than embodied carbon. Transferring the embodied energy figures to embodied carbon was found to be particularly challenging as it depends on the fuel used in each manufacturing facility. Where needed, the assumed carbon intensity of energy use, used in the review, was based on UK average total fuel consumption in 2005. These figures are derived from the DTI 2005 fuel split database and official DEFRA CO_2 intensities figures. The breakdown of each type of fuel use in 2005 is weighted against CO_2 intensity figures, producing an average figure of 0.23 kg CO_2/kWh.

The key findings of the literary review are summarised in Tables 5.1 and 5.2. It can be seen that carbon payback periods for energy efficiency measures and renewable energy technologies are generally low in comparison to the life expectancy of the plant or material.

The literature also suggests that future improvements in product performance and efficiencies in the projection process will further reduce the embodied carbon in renewable energy technologies. The three key factors affecting this are; improving efficiencies in manufacturing processes, a drive towards selecting more environmentally friendly materials, and a shift in fuel mix used as new policies in renewable energy sources are introduced. Estimates have been made for future improved payback periods (in terms of embodied carbon) of up to 50% for PV systems. For wind turbines embodied carbon can be reduced by replacing primary aluminium with recycled aluminium (which can reduce carbon payback periods by up to a third), or by replacing major aluminium parts with steel (which can reduce embodied carbon by up to 15%).

In conclusion, the implementation of energy efficiency measures and the addition of renewable energy technologies will increase the embodied carbon of a building and as operational carbon emissions are reduced the carbon embodied in these materials becomes a larger proportion the overall carbon footprint. However, this increase in embodied carbon should not act as a barrier to the uptake of renewable energy technologies or the promotion of a policy encouraging zero carbon, as the carbon savings generated by these technologies would always outweigh the increase in embodied carbon. The savings in carbon emissions from operational energy demands means that the increased embodied carbon is quickly recouped with typical payback periods of less than 4 years. This payback is set to further reduce as future improvements are made to reduce embodied energy and increase operational efficiency of renewable technologies.

Table 5.1: Embodied energy in energy efficiency products

Measure/ Technology	Definition of Systems	Range of Embodied Carbon (kgCO_2/m^2)	CO_2 Payback (yrs)	Key Variables (that affect embodied CO_2)
Insulation to achieve advanced practice standards	• Additional insulation in external walls/roof and ground floors. Assume mineral wool (150mm) in masonry homes	~6 kg CO_2/m^2 (approx 768 kg per home)	~3 years	• Choice of insulation material • Ability to achieve other construction standards required for advanced practice (eg levels of air tightness)
Insulation to achieve advanced practice standards	• Additional insulation in external walls/roof and ground floors. Assume mineral wool (300mm) in masonry homes	~12 kg CO_2/m^2 (approx 1,536 kg per home)	~2.5 years	• Choice of insulation material • Ability to achieve other construction standards required for advanced practice (eg levels of air tightness)

Table 5.2: Range of figures in literature for embodied carbon in Low and Zero Carbon technologies

Measure/ Technology	Definition of Systems	Range of Embodied Carbon (kgCO_2/m^2)	CO_2 Payback (yrs)	Key Variables (that affect embodied CO_2)
PV Thin Film	• BOS Included • Support Structure Included • Efficiency 10% • Glass Laminated • Roof Mounted	29-107 kgCO_2/m^2	1-4 years	• Manufacture (Deposition methods) • Material Use • Framed or Building Integrated System • Can produce entire modules in one process • Less efficient systems than crystalline
PV Crystalline *Multi Crystalline* *Mono Crystalline*	• BOS Included • Support Structure Included • Efficiency 13-14% • Glass Laminated • Roof Mounted	101-599 kgCO_2/m^2	2-5 yrs Multi Crystalline 2-10 yrs Mono Crystalline	• Manufacturing process (winning & purification of silicon wafers) • Framed or Building Integrated Systems • Need to process individual wafers • Production of silica appropriate for PV or creating wafers from molten silica, prevents further processing
Wind Large Scale	• Vestas V90-3MW • Onshore • 105m Steel plate towers • Concrete Foundations	1,792,850kgCO_2 (1792 tonnes CO_2) per 3MW turbine	1 year	• Construction Materials Used • Recycling potential of materials post use (this can reduce embodied carbon by 30%)
Wind Micro	• Swift 1.5kW • Roof Top Mounted • 2m Diameter Rotor • 10m Hub Height	2427kgCO_2/per Swift	13-20 months	• Material use (replacing primary aluminium with recycled aluminium or replacing major aluminium parts with Steel) • Potential for recycling components post use
Solar Thermal	• Absorbing collector • Water tank • Support for roof fastening	397-1061 kgCO_2/m^2	2-3.5 yrs	• Material Use (Aluminium & copper are very energy intensive but can have a high recycled content) • Mix of thermal fluid (Proportion of Glycol will affect CO_2 emissions) • Whether it is a gas or electric boosted system

Source: Supporting and delivering zero carbon development in the South West, January 2007. Faber Maunsell and Peter Carpenter.

5.5 Impact on supply of biomass fuel

Based upon an analysis of Annex A the *UK Biomass Strategy*, dated May 2007, we have estimated that the estimated existing UK biomass resource totals in the order of 13.5million oven dried tonnes (ODT).

Table 5.3 summarises the potential demand arising directly from the proposed Policy. For the purposes of this comparison, the figures from the Base case (Option 1) are used.

Table 5.3: Estimate of potential increased Biomass fuel demand arising from Policy

Year	Biomass required (in GWh)	Biomass required (in ODT)	Biomass required (as % of UK existing biomass resource)
2011	10	1,935	0.01%
2014	16	3,097	0.02%
2017	1,875	362,903	2.69%
2020	7,645	1,479,677	10.96%
2025	17,655	3,417,097	25.31%

It should be noted that, for the purposes of this comparison, the total resource figure includes all 'dry' materials (such as wood wastes, energy crops and garden plant waste). Poultry manure, sewage sludge and paper and card are excluded.

Also, the estimated figures provided in the Biomass Strategy document include existing used and unexploited resources but do not take account of potential growth in energy crops.

The short or medium term impact of growth in demand for biomass on its price per kWh of energy has not been factored in to this analysis.

5.6 Impact on technology supply

The results show that up until 2016 the performance improvements required by the considered policy options can be achieved, relatively cost effectively through a mix of technologies, including PV, wind (especially micro wind), biomass heating, solar water and also improved energy efficiency measures, at least to EST Best practice standards.

No one particular technology dominates in these years, suggesting that industry should be able to develop to meet demand in a manner which minimises problems from over demand, eg potential for increased costs together with excessive lead time, etc.

After 2016, the situation, based upon current assumptions, may be slightly different. Ignoring for the moment those policy options which permit off-site renewable energy generation, three technologies tend to predominate, namely PV, biomass CHP and wind.

The global market for PV is anticipated to grow along a similar route to that in the UK. This should ensure a security of supply for the UK market, albeit that large scale development, in particular, may have to rely on the involvement more of global multi-national rather than local suppliers.

Where biomass systems are used, surety of fuel supply and potential conflicts with local air quality policies are the main sources of risk. Fuel supply is discussed in section 5.3.2 above.

Where medium/large wind technology is possible, this is the most cost effective carbon reduction option. However, wind also has its own locational sensitivities and the number of sites in England where the use of medium to large scale turbines is possible or desirable remains to be seen. In this research the applicability of medium and large scale wind was limited to 20% of the developments where it might be considered feasible (ie the Market Town and Urban Regeneration scenarios). No such limitation was applied to the calculation of off-site renewable energy scheme and it was assumed that sufficient additional off-site renewable resource would be available in 2016 to enable off-site technologies to meet the policy objectives under options 3, 3a, 4 and 4a.

5.7 Small Firms Test

Small firms are most likely to be involved in the development of sites akin to the Small Scale and City Infill scenarios used in this study. It is the small sites which may see the highest cost increase due to the reduced scope for realising the benefits of scale in both technology selection and pricing.

In the short term, the production costs for smaller firms may be disproportionately higher. It is expected, however, that this impact will reduce over time as the new technologies become more established.

They will also potentially take longer to develop the most cost effective solutions than larger firms (although it might also be argued that they will be better placed to respond given that they have less complex supply chains and typically have less standardised products).

5.8 Effect on Existing Housing Stock

This research is concerned with achieving zero carbon within new build developments, however at present new housing accounts for only about 5% of the total housing stock in the UK each year.

Most of the technologies considered in this research can be applied to existing as well as new housing stock, although factors such as the design configuration, location mean that they might not be as cost effective.

Analysis of the additional impact of the policy options on the price of key technologies indicates that the options generally have relatively little additional impact on technology price (as shown in Table 5.4). This is because of the overwhelming significance of global production volumes on technology cost. The only exceptions are the measures required to meet the two energy efficiency standards. However, these standards will only to be applicable in part in existing stock (ie encouraging the use of higher quality glazing or the application of higher standards to extensions). Without the unified suite of measures provided by the Best and Advanced Practice standards the benefit of individual measures will be reduced.

Table 5.4: Direct impact of policy Option 1 on the cost of technologies in 2025

Technology	Percentage reduction in cost attributable to Policy Option 1 by 2025
EST best	4.86%
EST ad	19.30%
SWH	0.00%
PV	0.09%
Biomass heating	0.63%
Biomass CHP	0.04%
Micro wind	0.32%
Medium wind	0.04%
Large wind	0.06%
GSHP	0.00%
Gas CHP	0.00%

As a result it is unlikely that any of the policy options will have the effect of single-handedly reducing technology prices to the extent that they are adopted by mainstream owners of existing housing. Nonetheless, even a small contribution to increasing uptake in existing housing stock could realise a benefit in terms of reduced carbon emissions. A potentially more significant impact of the uptake of low carbon technologies in new housing would be to create additional consumer awareness of what can be achieved and to increase the acceptability/demand for low carbon housing. This could encourage more owners of existing homes to invest in their own low carbon technology.

Other technologies, particularly those that rely in centralised infrastructure, may also suffer from similar restrictions. However there may be potential for new developments to link with suitable existing housing (eg apartment blocks) or commercial/retail/leisure space to deliver carbon savings on a larger scale with reductions in relative cost for all parties.

5.9 Potential role of ESCOs

The involvement of ESCOs has the potential to enable developers to offset some of the initial costs of low carbon technologies with the service provider making their return through a long term supply contract.

Consultation with ESCO companies previously indicated that the minimum scale of development which would sustain a business case for ESCO involvement would be in the order of 300 dwellings. This number may be slightly reduced on schemes with a non residential element. However, as the research included only one development scenario of greater than 100 units, a detailed study of ESCO viability and benefit was outside the scope.

With the exception of biomass CHP in the City Infill scenario, all of the low carbon options considered deliver operational cost savings in comparison to traditional alternatives[21] after the capital cost has been discounted. However, an important test is whether the scale of these savings is sufficient to fund replacement of the technology at its end of life. By estimating the present value of energy savings arising over 40 years (the duration of some ESCO contracts) and comparing these to the present value of maintenance and replacement costs it is possible to achieve overall savings for:

- PV
- Ground Source Heat Pumps
- Biomass heating
- Gas CHP (for Market Town and Urban Regeneration developments)
- Biomass CHP (for Urban Regeneration developments)
- Medium and large scale wind turbines

This suggests that, given a sufficiently long management period, it should be possible to maintain the zero carbon status of homes built once they have been built to this standard. However, it should be stressed that this assessment does not replicate the intricacies of an ESCO business model which would include a range of complex financing arrangements.

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[21] ie a gas fired condensing boiler

The consultation carried out as part of the research suggested that for large scale development, within which the large scale technologies could be utilised, such as biomass CHP, gas CHP and wind, a high level business case exists for ESCO involvement which would offer both long terms fuel bill reductions to occupiers, and allow for a capital contribution toward the initial installation of the plant and replacement at the end of its useful life. This is achieved by considering the marginal discounted maintenance and replacement costs together with marginal revenues over a minimum of 35 years.

5.10 Opportunities and potential for further refinement of the cost and benefits modelling

The research is based upon a mix of development scenarios considered to be representative of the scale and mix of single plot developments in England.

The policy options modelled were selected in conjunction with Communities and Local Government in May 2007, as being representative of the most likely strategies for the implementation of zero carbon in new build housing by 2016.

Consideration of very large scale development, such as Eco-towns, or developments of up to say 8,000 to 10,000 fall outside the scope of the research. However, it is likely that considering the implementation of zero carbon policy at this scale may lead to different solutions becoming viable, such as large scale waste to energy solutions, giving the opportunity, therefore, for a significant reduction in costs and the generation of much greater benefits.

Other suggested refinements to the analysis could include;

- Reviewing the basis of the DER calculations, to reflect the proposed policy changes regarding the use of secondary heating and low energy lighting from 2011
- Alternatively, the impact of allowing recourse to off-site solutions after the implementation of a 44% carbon reduction target in 2013
- Running the models based upon alternative levels of fuel cost
- Assessing the impact on outlining housing types such as very large homes, bungalows or townhouses.

The dynamic cost and benefit model established in this study should facilitate the analysis of these options, although it would require some minor adjustments to the optimisation process.

Consideration could also be given to emerging technologies, such as fuel cells, or smaller scale application of existing technologies (such as biomass CHP) making them applicable to a wider range of development types.

It may also be seen that, whilst over the long term, the learning rate assumptions upon which the research is based are considered reasonable, in the short to medium term, individual technologies may see more dramatic changes on cost reduction, in response to changes on market demand, technological innovation etc.

In terms of the policy itself, a range of carbon reduction measures have been proposed by central government during the period covered by this research (see section 5.10) these would have the impact of reducing the modelled electricity demand of new housing and could result in instantaneous reduction in the baseline carbon emissions of a new home by 10%. Similarly measures to enhance the energy efficiency of domestic appliances such that the level of unregulated emissions decreases over time could help reduce the cost of compliance with a zero carbon target.

Section 6: Conclusions

This research considers a range of alternative approaches to the implementation of the Government's policy for all new build dwellings to achieve zero carbon status from 2016.

The research uses a modelling process to find the most cost effective mix of low carbon technologies that will reduce the carbon emissions of dwellings sufficiently to achieve the code level required in any given year.

This process is 'dynamic', in that the technologies selected in one year affect their predicted cost in the following year because of the influence of uptake on technology costs. This optimisation is carried out separately for each development type, dwelling type and sector (ie for affordable housing and housing for sale) and year.

Any one of a number of the factors considered in the modelling process can influence the overall results. In the extreme, the sensitivity analysis showed that overall costs could fluctuate from –50% to +32% against the medium assuming either all factors considered were realised at either their lowest or alternatively their highest current forecast projections.

Consequently, the results of this research should not be deemed as definitive, but as projections based upon a reasonable forecast assessment of future trends wherever possible utilising published data.

6.1 Environmental benefits

Whichever policy alternative is ultimately taken forward, the amount of CO_2 saved per annum by 2020 is broadly consistent, ranging between 2.62 Mt to 3.16 Mt. Further, by 2050, the dwellings built up to 2025 will save an estimated 6.2 Mt per annum or 195 Mt in total[22]. If construction rates continued at 2025 levels through to 2050 then the carbon saving achieved in comparison to current practice could be 21.5 Mt per annum in 2050 or 392 Mt in total.

Annex B of the DTI document *Meeting the Energy Challenge – A White Paper on Energy*, May 2007 estimates that by 2020 UK energy generation could total 367 TWh based upon Central policy estimates. From the modelling, it is estimated that, by 2020 the total of electrical energy being generated by renewable sources as a direct consequence of the policy could total 5.2 TWh; equivalent to approximately 1.4% of the total UK electrical energy projection.

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[22] Assuming that they maintain their zero carbon status in perpetuity.

With the exception of the City Infill scenario, all of the development types modelled were able achieve zero carbon using on-site technologies. Analysis of the shortfall in carbon reductions arising on the City Infill sites showed that it is also possible to achieve zero carbon status for this scenario using on site technologies, but that this would require careful redesign to increase the area of roof/exposed surface on which PV could be placed.

Embodied carbon should not act as a barrier to encouraging zero carbon housing developments under the policy, with carbon payback on technology options being achieved within a small fraction of their overall lifespan.

6.2 Financial benefits

6.2.1 Using only on-site technologies

For options relying on on-site technologies only, the construction costs of achieving zero carbon in 2016 are likely to be between 17% and 24% higher than the costs for dwellings built to the standards of Building Regulations Part L1a 2006, but this should fall in future years, as learning rates reduce the cost of low carbon technologies. By 2025 the increase in compliance costs would be between 14% and 18%.

Translating these costs into a total net present cost associated with the application of a full on-site policy to all dwellings projected to be constructed to 2025, gives an estimated range of £10,250m to £14,452m, depending upon the policy option.

Improved energy efficiency together with reduced reliance on grid supplied electricity means that annual fuel bill savings of up to £387 per annum could be achieved. However, it is likely that part (or the majority) of these savings could be taken up in the maintenance and management of the technologies involved.

6.2.2 Allowing some use of off-site technologies

Allowing part of the required carbon reduction after 2016 to be achieved through contributions to off-site renewable energy schemes has a significant impact on both the costs and benefits of the policy.

Where off-site contributions are allowed after 2016 the overall costs of the policy could be as low as £4.0 billion (or £1.0 billion after carbon benefit). However, any approach based upon carbon reduction being taken off-site would deliver much lower tangible benefits to homeowners in fuel bill savings, overall operational cost reductions and arguably, the quality of their housing.

The impact of allowing unqualified levels of off-site contributions after 2016 is to remove any incentive to continue to build to higher levels of energy efficiency. This is seen in the results, whereby, the construction costs drop back to a level reflective of current standards (see Options 3 and 3a) and all carbon reduction (with the exception of large scale wind) is achieved off-site. This means that there is no saving in homeowner fuel bills over the current position.

Even with the inclusion of an energy efficiency backstop (at EST Advanced Practice), fuel bill savings do not exceed £190 per annum when off-site solutions are allowed to deliver the majority of the required carbon reduction. Nonetheless, the relative impact of these options on capital costs is much lower with the percentage increase on current requirements at between 5.3% (Option 3) and 13.3% (Option 4a) in 2016.

As would be expected, the results based upon optimising on total costs and benefits over the life time of an asset generate lower costs overall, however this is not significant post 2016.

6.3 Technological impact

Up to 2016 the performance improvements required by proposed policy can be achieved, relatively cost effectively through a mix of technologies, including PV, wind (especially micro wind), biomass heating, solar water and also improved energy efficiency measures, at least to EST Best practice standards.

No one particular technology dominates in these years, suggesting that industry should be able to develop to meet demand in a manner which avoids problems of over demand, excessive supply periods, etc.

Excluding the use of micro wind had only a marginal effect on the results.

After 2016, the situation, based upon current assumptions, may be slightly different. Ignoring for the moment those policy options which permit off-site renewable energy generation, three technologies tend to predominate, namely PV, biomass CHP and wind.

These results show that even with the progressive implementation of the policy (with changes in performance standards in 2010, 2013 and 2016) it is still likely that there will be changes in the core carbon saving technology post 2016, ie the solutions that deliver the standards required post 2010 and 2013 may not effectively prepare the industry to deliver zero carbon post 2016. Therefore, while the incremental introduction of the policy should afford industry the opportunity to prepare for the change to zero carbon, it does not provide a smooth learning curve arising from increasing application of the same technologies and as a result is not the optimal preparation for achieving the zero carbon standard.

The predominance of biomass CHP in the results post 2016 is significant. This is currently still an emerging technology. Its long term viability would also clearly be sensitive to the stability of the supply and price of the fuel.

It should also be noted that there is likely to be an anomaly in the overall costs where biomass CHP is used in conjunction with very high mandatory levels of energy efficiency (eg the current Code for Sustainable Homes Level 6 requirement). A cost increase was seen where EST Advanced Practice measures are made mandatory because this simultaneously reduces the potential for carbon reductions through biomass CHP systems (because of the reduced heating load in these dwellings). This should not preclude a commitment to higher energy efficiency standards, because it does still deliver greater real reductions in energy consumption, if not greater carbon savings. It may, however, move the balance away from locally generated carbon reduction solutions to site or district wide schemes.

Wind also has its own considerations in terms of sensitivity to location factors and the number of sites in England where the use of medium to large scale turbines is possible remains to be seen.

6.4 Potential for replacement of LZC technologies at the end of their service life

If the capital cost is written off all of the low carbon options considered deliver operational cost savings in comparison to traditional alternatives[23] (with the exception of Biomass CHP in the City Infill scenario). However, an important test is whether the scale of these savings is sufficient to fund replacement of the technology at its end of life.

By estimating the present value of energy savings arising over 40 years (the duration of some energy services company (ESCO) contracts) and comparing these to the present value of maintenance and replacement costs it is possible to achieve overall savings for:

- PV
- Ground Source Heat Pumps
- Biomass heating
- Gas CHP (for Market Town and Urban Regeneration developments)
- Biomass CHP (for Urban Regeneration developments)
- Medium and large scale wind turbines

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[23] ie a gas fired condensing boiler

This suggests that, given a sufficiently long management period, it should be possible to maintain the zero carbon status of homes once they have been built to this standard. However, it should be stressed that this assessment does not replicate the intricacies of an ESCO business model which would include a range of complex financing arrangements.

6.5 Sensitivity to energy price changes

The results presented in this study assume that energy prices do not change over the duration of the study period. To assess the impact of different energy price trends, the costs and benefits of the Base Case policy (Option 1) were modelled using two alternative price scenarios[24]. The results indicated that, although total capital costs were the same for each scenario, the comparative life time costs reduced significantly with increasing energy projections (thereby increasing the overall benefit of the policy). Conversely, the comparative life time costs increased significantly with decreasing energy projections (thereby reducing the overall benefit of the policy). The high energy price scenario indicated that in a scenario of year on year energy price increases, the overall comparative NPV of Option 1 could reduce by up to 16.5%. However, the low energy price scenario indicated that in a scenario of year on year energy price decreases, the overall comparative NPV of Option 1 could increase by up to 29%.

Clearly, future energy prices are highly uncertain. However, the results indicate that the net cost of the policy is highly sensitive to change in energy prices and particularly the differential costs of gas and biomass fuels.

6.6 Pricing of energy sold into the grid

The modelling undertaken in this study assumes that all of the energy generated within a development can be used within the development or sold into the grid at a competitive price. At present relatively few utilities are prepared to purchase locally generated electricity at retail prices and it could be assumed that this would become increasingly rare as the quantity of locally generated energy increases. Therefore, on sites where there is likely to be a considerable amount of energy exported from the site during the year the value of the annual reductions in fuel bills could be less than those estimated here.

6.7 Eligibility for Renewables Obligation Certificates (ROCS)

A further consideration is whether renewable energy installed to achieve Building Regulations standards will be eligible for ROCs. In this study it is assumed that new homes are not eligible for income from the sale of ROCs, because doing so would remove the additionality of the carbon savings achieved. Nonetheless, in practice, it could be difficult to distinguish between renewable energy generated

[24] projected price change profiles were developed using Communities and Local Government indicative data on average price of domestic fuel for the period 2006 to 2020

to meet a Building Regulations requirement and that installed for other reasons (for which ROCs would be eligible). Therefore, for administrative clarity it may be necessary for all domestic renewable energy to be eligible for ROCs.

If this were the case it would be necessary to re-evaluate the operation of the Renewables Obligation to review the options for securing additionality for credits obtained by new housing and to determine responsibility for funding the additional ROCs required.

If all domestic renewable energy generation were eligible for ROCs then the benefits of renewable technologies would increase in comparison to energy efficiency measures and the business case for ESCO involvement in the supply and maintenance of renewable technologies would be strengthened.

6.8 Development scale

Costs are also expected to be higher for smaller developments (because more cost effective site wide solutions are less applicable) and, therefore, costs may be higher for smaller firms which would have a greater exposure to smaller scale developments.

Whilst it is expected that this impact will reduce over time, it is anticipated that the highest levels of efficiency will be achieved on larger sites. This could mean emphasis on mixed use developments or, indeed, the aggregation of small developments to a scale which could facilitate either on-site solutions in a cost effective way or the involvement of ESCOs or MUSCOs.

6.9 Risks

The key influence on the financial viability of developments relates to the potential dislocation between developers exposure to higher capital cost and the ability to recoup this from either higher sales values (as homeowners capitalise the value of future savings in fuel bills). Separate research by Element Energy for the Energy Saving Trust[25] suggests that homeowners typically use high discount rates of up to 20% when valuing benefits such as energy savings. The majority of the policy costs may be borne by developers (or ultimately landowners) with homeowners receiving the additional benefits. The potential involvement of an Energy Services Company (ESCO) could present a mechanism for financing the initial capital costs against the stream of future revenues. However in practice ESCO involvement in small sites or where technology paybacks are marginal could be difficult.

Policy options 1(a), 2(a) and 5(a) could, therefore, add to developers up front financing cost and associated risk.

[25] *A Model for Microgeneration Technology Purchase in the UK*: draft report for review. April 2007.

Adaptation to new technologies on a large scale will require re-training of existing labour and recruitment of new operatives and installers to meet demand across the construction industry.

The structure of the market for electricity may also be influenced. At present, home owners have freedom of choice in respect of their energy suppliers. This freedom may be limited in future, where dwellings could conceivably be tied to a particular ESCO for heat (and potentially power). If ESCOs are to be encouraged to invest in new developments they will need some surety of future demand for electricity as well as heat if they are to raise finance effectively. At present the 28 day rule means that homeowners can change electricity suppliers rapidly. This is not too great a risk where the percentage of power generated on-site is relatively low, but as it increases towards net 100% it could become a far more significant issue.

The systems modelled are assumed to be based around a private wire distribution system[26]. These systems are generally more expensive to install but draw greater income from electricity sales. Nevertheless, sites will still need to be connected to the grid to provide supplies for peak demand and even if a site is net zero carbon over a year it will still need to draw on energy from the grid on a regular basis (replacing this energy at times of surplus). Given that the price of energy sold into the grid is governed by a number of factors such as timing, quantity and predictability, it could be difficult for a single site to achieve significant revenue from energy sold into the grid. Therefore, uncertainty in the surety of demand and the inability to 'net meter' may act as a disincentive to ESCO involvement as the overall expectation of on-site generation rises to net 100%.

As can be seen from the results of the research, there is a clear possibility that after 2016, a smaller number of technologies may predominate. These include PV, wind (both on-site and off-site) and biomass CHP. These technologies considered are, in many cases, untested on a large scale. And it will be important that in preparing for the step to zero carbon sufficient resource is provided to testing the merits of alternative strategies, initiatives such as the Carbon Challenge provide a valuable test bed.

Fuel supply will need to be kept under review. The likely demand for biomass fuel arising directly from the policies considered in this research is discussed elsewhere in this section. This should be reviewed in conjunction with demands arising from other sectors and elsewhere in the built environment.

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[26] This is where the ESCO owns and maintains the distribution infrastructure across the whole site and is therefore able to distribute power around the site without it passing through the grid. A private wire system (especially where there is a mix of uses) therefore enables a greater proportion of locally generated electricity to be used internally rather than exported to the national grid.

6.10 Priorities for further analysis

This is one of the first pieces of research to consider the implications of achieving zero carbon housing in England. Significant further work is required to address some of the key issues arising, including:

- How can the technology trajectory between 2008 and 2016 be made as smooth as possible
- To what extent and under what conditions should off-site renewable sources be used to supplement/replace those used on-site
- What are the wider implications of encouraging the widespread adoption of biomass based technologies throughout the UK
- How can the predicted expansion of locally generated electricity be integrated within existing regulatory regimes and the Renewables Obligation as currently structured
- The role of ESCOs in delivering zero carbon developments.

Appendix A: Base Modelling Assumptions

This appendix summarises additional information regarding source data and assumptions used in the research, not otherwise referred to in the main sections of the report

A1 Build projections

Projections for new build housing over the period 2008 to 2025 is derived from

- Communities and Local Government statistics Table 232 Housebuilding: permanent dwellings completed, by tenure and region
- Communities and Local Government statistics Table 252 Housebuilding: permanent dwellings completed by house and flat, number of bedroom, tenure and region
- Kate Barker's *Review of Housing Supply*, published in 2004

Development types and dwelling mix derived from NHBC data on housing registrations and development plot sizes in 2006

- Social housing numbers derived from historic data obtained from Communities and Local Government and the Homes and Communities Agency's projections to build around 40,000 homes per year
- Data on current and predicted numbers of PassivHaus standard homes is provided by the PassivHaus Institute.

A2 Learning rates

Data on UK and global learning rates is derived from:

- Microgeneration technologies:
  - The Energy Saving Trust, Econnect and Element Energy Report *Potential for Microgeneration Study and Analysis* dated 14 November 2005.
  - Larger scale onsite generation technologies:
  - The report *Supporting and delivering zero carbon development in the South West*[27].
- Off-site renewable energies:
  - The National Audit Office report *Economic Analysis of the design, cost and performance of the UK Renewables Obligation and capital grants scheme*[28].

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[27] Faber Maunsell, 2007.

[28] OXERA, 2005.

- Energy efficiency. Information on learning rates is identified from Swiss and UK researchers; key sources include:
- The CEPE report *Exploring Experience Curves for the Building Envelope: An Investigation for Switzerland for 1970-2020*
- The OXERA report *Results of renewables market modelling* (2004).

Appendix B: Carbon Saving Technologies

B1 Overview

Where applicable, energy efficiency measures and renewable energy technologies were modelled using the Government's approved calculation methodology (SAP 2005) to calculate their potential for CO_2 saving against a base case dwelling type specified to meet ADL1a 2006.

Three levels of energy efficiency are considered;

- current ADL1a 2006 compliance
- Energy Savings Trust Best Practice standard
- Energy Savings Trust Advanced practice standard.

The LZC technologies considered were;

- Solar Water Heating
- Photovoltaics
- Gas fired community heating
- Gas fired CHP
- Biomass community heating
- Biomass CHP
- Ground Source Heating
- Micro Wind
- Medium Wind
- Large Scale Wind

Micro CHP was not considered in this research as the current SAP database does not include any commercially available systems. Air source heat pumps[29] were also outside the scope of this research.

Each technology is modelled separately against the three energy efficiency standards.

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[29] There is some debate about whether air source heat pumps are a renewable technology. However it is our understanding that they only generate savings when the outside air temperature is above c. 4°C. At other times they rely on a back up electric immersion heater and as a result over the course of a typical year generate little, if any, CO_2 savings against a base case house using gas central heating.

Wherever possible, the SAP defaults have been used to calculate the CO_2 savings that can be achieved from each technology. SAP does not currently take account of energy generation from wind turbines so the research assumes outputs from turbines of different sizes. Assumption is also made as to the number of dwellings which would benefit from wind generated electricity.

The model attempts to ensure that the CO_2 emissions (calculated based upon SAP energy outputs) when divided by the unit floor area match as closely as possible with the Dwelling Emission Rate (DER); it is understood future regulatory updates will be based on a percentage reduction for DER against the TER as is the case under the current Part L of the Building Regulations. For this reason, it was assumed in the SAP modelling that 10% of space heating demand would be provided by electric room heaters and that only 30% of light fittings would be energy efficient, as assumed within the DER calculation. The estimate of regulated CO_2 emissions from SAP can be combined with the CO_2 emissions estimated for appliance and cooking to give the overall household CO_2 emissions and, for the policy options, the savings against current standards.

Ground Source Heat Pumps (GSHP) rely on electric fuel which has a different fuel factor under Building Regulations Part L1a 2006 meaning that the TER for this option is higher than in other options resulting in CO_2 savings against the TER appearing greater than they are in reality. In this research, we calculate the savings generated through use of GSHP against the same base as the other technology options to produce true CO_2 savings. This is something which may need to be reviewed further in future Building Regulation updates.

All technologies are modelled at a dwelling level. It is understood that because of the proposed energy performance certificates (EPCs) all dwellings will be required to comply with regulations separately and that the SAP methodology in time will be adjusted to deal with technologies which are more typically applied on a site wide basis. In the research, site wide technologies are sized against the four hypothetical development scenarios, with the costs for common installations apportioned against all units to arrive at a per dwelling cost. For example, a 50kW biomass boiler serving 18 flats on a City Infill development means that each flat requires 2.77kW installed capacity; the associated costs for this system are split across the total unit numbers on a pro-rata of internal floor area basis. The development scenarios also allow a check on the ratio of roof area to floor area to ensure the size of solar installations is appropriate.

Where appropriate, technologies are modelled against a minimum and maximum contribution to reflect the potential scalability of the technologies within different development scenarios. Scale is particularly important for electrical generating technologies such as PV and wind. Many of the heat producing technologies are applied at one size to meet the space and/or hot water demands.

B2 Energy efficiency solutions

For each of the house types, three levels of fabric performance have been modelled:

- ADL1a 2006 compliance
- EST Best Practice Energy Efficiency standard
- EST Advanced Practice Energy Efficiency standard

ADL1a compliant dwellings were deemed to meet the requirements of current Building Regulations only.

The EST Best and Advanced practice standards were based on the backstop performance criteria outlined in EST's guidance documents, published September 2006. For simplicity, the U values set out in this guidance were applied against all dwelling types, although in reality developers may be able to relax these standards, especially where combined with renewable energy and still achieve their target CO_2 reduction and the required heat loss parameter. The energy efficiency measures were applied in the modelling as 'packages' of measures including U value improvements, improvements above accredited details for the thermal bridging and increased air tightness. In the Advanced practice specification SAP Appendix Q is used to model the CO_2 savings achievable through specification of a high efficiency MVHR system. In reality, developers can mix and match these measures to achieve their targets. The model does not take account of this level of detail.

B3 LZC technologies; thermal

Solar Water Heating (SWH)

Solar water heating panels typically generate around 50% of household hot water demand. The research assumes the following aperture sizing:

Detached House:	$4m^2$
Mid Terrace:	$3.3m^2$
End Terrace/Semi:	$3.3m^2$
Flats:	$2.9m^2$

SAP default values were used to calculate potential CO_2 savings as a result of requiring less gas for water heating. The SAP calculations show savings of between $320kWh/m^2$ and $378kWh/m^2$ although there is also an increased space heating demand assumed and typically an additional electrical requirement for powering the solar pump. It was assumed that a PV powered solar pump would be used to reduce the pumping energy requirements. Modelling shows that SWH provides savings against regulated emissions of between 10.5 and 15% or about 7 – 9% of total household emissions.

Biomass Community Heating

The sizing regime assumes a central plant providing either 80% or 40% of the space and hot water requirement for the home. Only the 80% option was considered for the Small and City Infill scenarios because the commercial systems are not available for smaller systems. The primary district heating main feeds a Heat Interface Unit (HIU) in each home which provides heat for space heating and hot water supply. One unit of installed capacity is specified for each house type, however, this varies with the energy efficiency standard. Costs include the construction of fuel storage and ensuring good vehicle access. The price of delivery and boiler cleaning is dealt with within the fuel price.

For all community heating systems it is accepted that back up gas boilers may be installed as part of a community heating solution.

Ground Source Heating

The sizing regime will follow that described above for gas community heating. Ground source systems will be assumed to be community systems in the higher density scenarios (City Infill and Urban Regeneration). The modelling assumes the system uses underfloor heating as this gives a higher carbon reduction.

B4 LZC technologies: electricity

Photovoltaics

Maximum and minimum installation sizes have been set for each of the house types, with the maximum determined by the likely availability of roof area. We have assumed 50% of roof area on all blocks is south facing. This guide can be applied for flat roofs where panels will be mounted on racks. The racks angled at 30° do over-shade one another if located too close together, however, even with this spacing, 50% of the roof area can still be utilised for active panels.

Wind

The research considered three basic scales of wind turbine. Micro (building mounted), medium stand-alone and large scale. Micro for the purposes of this study was assumed as a 1.5kW turbine, with medium being around the 50kW scale and large around 2MW. The estimated savings from these technologies have been divided by an assumed number of homes to estimate the likely electrical contribution per home. The technology scales, turbine outputs and number of homes served can obviously significantly alter the renewables benefit per home. At this stage there is no approved method for calculating household energy savings from community turbines; assumptions were made based upon industry consultation, as follows:

- Medium scale turbine (50kW) – 150 MWh per annum serving 50 to 150 dwellings
- Large scale turbine (2MW) – 4GWh per annum serving 1000 to 2000 dwellings

B5 LZC technologies; Combined Heat and Power (CHP)

CHP systems for both gas fired and biomass fired CHP were modelled as meeting either 40% or 80% of total heating and hot water demand for the Market Town and Urban Regeneration scenarios. The remaining demand was assumed to be met by gas boilers. For the City Infill and Small scenarios only the 80% sizing option was considered due to the small capacity of the systems required.

Table B.1 summarises the key performance characteristics used for the different CHP systems used in the study.

Table B.1: Key performance characteristics of CHP systems

Technology and scale	Heat to Power ratio	Electrical efficiency (%)	Heat efficiency (%)	Comments
Gas CHP				
City Infill/ Small Scale	2.29	24	55	Based on Baxi Dachs reciprocating gas engines
Market Town	1.52	31	47	Based on 100kWe reciprocating gas engine
Urban Regeneration	1.36	33	45	Based on > 300kWe reciprocating gas engine with turbocharger
Biomass CHP				
City Infill/ Small Scale	15	5	75	Based on a Stirling engine unit, eg KWB 1kWe pellet unit
Market Town	2.0	20	40	Based on Talbotts gas micro-turbine
Urban Regeneration	2.0	20	40	Based on gasifier and gas engine

Appendix C: Results presented on a dwelling and development scenario basis

OPTION 1: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,322	£2,231	£3,062	£2,520
2014 (showing effect of policy in 2013)	£5,364	£3,661	£4,640	£3,857
2017 (showing effect of policy in 2016)	£19,181	£12,312	£11,991	£10,205
2025	£16,458	£10,794	£10,472	£8,820
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	3%
2014 (showing effect of policy in 2013)	7%	5%	6%	5%
2017 (showing effect of policy in 2016)	24%	17%	16%	14%
2025	21%	15%	14%	12%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,300	£6,608	£7,022	£6,887
2014 (showing effect of policy in 2013)	£5,671	£6,160	£5,855	£6,185
2017 (showing effect of policy in 2016)	£6,116	£5,400	£4,265	£4,290
2025	£5,248	£4,734	£3,722	£3,710

PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	PV	EST Best
Second	PV	PV	Medium Wind	PV
Third	–	–	EST Best	Biomass Comm
Fourth	–	–	–	EST Advanced

PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	PV	PV	PV
Second	PV	EST Best	Large Wind	EST Best
Third	–	–	Medium Wind	Biomass Comm
Fourth	–	–	EST Best	–

OPTION 1: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	PV	Biomass CHP	Biomass CHP	Biomass CHP
Second	Biomass Comm	Carbon Permits	Large Wind	PV
Third	Micro Wind	PV	PV	–
Fourth	EST Best	EST Best	–	–

LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	14%	12%	13%	14%

CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(78)	(46)
2014 (showing effect of policy in 2013)	(152)	(86)	(156)	(83)
2017 (showing effect of policy in 2016)	(400)	(178)	(341)	(228)
2025	(401)	(178)	(342)	(229)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				

NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(666)	(878)	(853)
2014 (showing effect of policy in 2013)	(1,276)	(1,144)	(1,670)	(1,237)
2017 (showing effect of policy in 2016)	(3,640)	£2,130	(1,265)	(3,797)
2025	(3,639)	£2,132	(1,265)	(3,797)

OPTION 1: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,149	£3,219	£2,942	£2,076
2014 (showing effect of policy in 2013)	£6,389	£4,774	£4,363	£3,394
2017 (showing effect of policy in 2016)	£17,618	£12,836	£12,065	£9,847
2025	£15,376	£11,179	£10,375	£8,588
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	4%	4%	4%	3%
2014 (showing effect of policy in 2013)	7%	7%	7%	5%
2017 (showing effect of policy in 2016)	19%	18%	18%	13%
2025	16%	16%	16%	12%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,907	£7,087	£7,769	£6,074
2014 (showing effect of policy in 2013)	£5,498	£6,214	£6,193	£5,711
2017 (showing effect of policy in 2016)	£4,884	£4,577	£4,606	£4,319
2025	£4,262	£3,987	£3,961	£3,767
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	13%	13%	14%	13%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(96)	(74)	(60)	(72)
2014 (showing effect of policy in 2013)	(185)	(123)	(113)	(154)
2017 (showing effect of policy in 2016)	(404)	(322)	(308)	(304)
2025	(405)	(323)	(309)	(305)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,112)	(832)	(775)	(698)
2014 (showing effect of policy in 2013)	(2,308)	(1,457)	(1,323)	(1,185)
2017 (showing effect of policy in 2016)	(1,994)	(1,677)	(1,981)	(1,491)
2025	(1,994)	(1,676)	(1,981)	(1,491)

OPTION 1a: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,325	£2,233	£3,327	£5,707
2014 (showing effect of policy in 2013)	£5,372	£3,667	£5,147	£5,545
2017 (showing effect of policy in 2016)	£19,372	£12,324	£12,024	£10,264
2025	£16,461	£10,786	£10,508	£8,881
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	8%
2014 (showing effect of policy in 2013)	7%	5%	7%	7%
2017 (showing effect of policy in 2016)	24%	17%	16%	14%
2025	21%	15%	14%	12%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,309	£6,613	£4,574	£6,391
2014 (showing effect of policy in 2013)	£5,679	£6,170	£5,014	£6,110
2017 (showing effect of policy in 2016)	£6,171	£5,405	£4,279	£4,322
2025	£5,248	£4,731	£3,737	£3,746
PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	Large Wind	Gas CHP
Second	PV	PV	PV	–
Third	–	–	ESTBest	–
Fourth	–	–	–	–
PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	PV	PV	Gas CHP
Second	PV	EST Best	Large Wind	–
Third	–	–	Gas CHP	–
Fourth	–	–	EST Best	–

OPTION 1a: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	PV	Biomass CHP	Biomass CHP	Biomass CHP
Second	Biomass Comm	Carbon Permits	Large Wind	PV
Third	Micro Wind	PV	PV	Gas CHP
Fourth	EST Best	EST Best	EST Best	–
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	15%	12%	13%	13%
CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(123)	(187)
2014 (showing effect of policy in 2013)	(152)	(86)	(199)	(189)
2017 (showing effect of policy in 2016)	(349)	(133)	(253)	(134)
2025	(342)	(134)	(254)	(136)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(665)	(1,690)	(4,378)
2014 (showing effect of policy in 2013)	(1,276)	(1,143)	(2,557)	(4,406)
2017 (showing effect of policy in 2016)	(3,798)	£2,129	(1,346)	(3,859)
2025	(3,638)	£2,136	(1,344)	(3,890)

OPTION 1a: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,382	£3,465	£3,194	£3,160
2014 (showing effect of policy in 2013)	£6,431	£4,883	£5,710	£3,938
2017 (showing effect of policy in 2016)	£17,729	£12,847	£12,098	£9,913
2025	£15,381	£11,192	£10,392	£8,665
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	5%	5%	5%	4%
2014 (showing effect of policy in 2013)	7%	7%	9%	5%
2017 (showing effect of policy in 2016)	19%	18%	18%	13%
2025	16%	16%	16%	12%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£5,326	£4,787	£5,399	£4,801
2014 (showing effect of policy in 2013)	£5,493	£5,023	£5,553	£4,980
2017 (showing effect of policy in 2016)	£4,914	£4,581	£4,623	£4,348
2025	£4,264	£3,994	£3,971	£3,801
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	13%	13%	14%	13%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(129)	(116)	(102)	(135)
2014 (showing effect of policy in 2013)	(190)	(157)	(193)	(200)
2017 (showing effect of policy in 2016)	(293)	(236)	(235)	(240)
2025	(290)	(238)	(235)	(241)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,816)	(1,557)	(1,474)	(2,127)
2014 (showing effect of policy in 2013)	(2,392)	(2,036)	(3,111)	(2,406)
2017 (showing effect of policy in 2016)	(2,089)	(1,677)	(2,005)	(1,675)
2025	(1,994)	(1,692)	(2,005)	(1,671)

OPTION 2: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,322	£2,231	£3,062	£2,520
2014 (showing effect of policy in 2013)	£3,052	£2,010	£2,630	£2,271
2017 (showing effect of policy in 2016)	£19,240	£12,333	£12,006	£10,221
2025	£16,473	£10,799	£10,476	£8,824
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	3%
2014 (showing effect of policy in 2013)	4%	3%	3%	3%
2017 (showing effect of policy in 2016)	24%	17%	16%	14%
2025	21%	15%	14%	12%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,300	£6,608	£7,022	£6,887
2014 (showing effect of policy in 2013)	£6,259	£5,952	£6,051	£6,132
2017 (showing effect of policy in 2016)	£6,135	£5,409	£4,271	£4,296
2025	£5,253	£4,737	£3,723	£3,711
PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	PV	EST Best
Second	PV	PV	Medium Wind	PV
Third	–	–	ESTBest	Biomass Comm
Fourth	–	–	–	EST Advanced
PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	PV	PV
Second	PV	PV	Medium Wind	ESTBest
Third	–	–	ESTBest	Biomass Comm
Fourth	–	–	–	EST Advanced

OPTION 2: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	PV	Biomass CHP	Biomass CHP	Biomass CHP
Second	Biomass Comm	Carbon Permits	Large Wind	PV
Third	Micro Wind	PV	PV	–
Fourth	ESTBest	ESTBest	–	–

LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	14%	12%	13%	14%

CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(78)	(44)
2014 (showing effect of policy in 2013)	(82)	(45)	(78)	(44)
2017 (showing effect of policy in 2016)	(341)	(133)	(246)	(131)
2025	(342)	(134)	(247)	(132)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				

NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(666)	(878)	(853)
2014 (showing effect of policy in 2013)	(741)	(659)	(876)	(737)
2017 (showing effect of policy in 2016)	(3,640)	£2,130	(1,265)	(3,797)
2025	(3,639)	£2,132	(1,265)	(3,797)

OPTION 2: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,149	£3,219	£2,942	£2,076
2014 (showing effect of policy in 2013)	£3,632	£2,786	£2,496	£1,878
2017 (showing effect of policy in 2016)	£17,647	£12,858	£12,091	£9,860
2025	£15,383	£11,185	£10,381	£8,591
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	4%	4%	4%	3%
2014 (showing effect of policy in 2013)	4%	4%	4%	3%
2017 (showing effect of policy in 2016)	19%	18%	18%	13%
2025	16%	16%	16%	12%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,907	£7,087	£7,769	£6,074
2014 (showing effect of policy in 2013)	£5,999	£6,557	£6,590	£5,493
2017 (showing effect of policy in 2016)	£4,892	£4,585	£4,616	£4,325
2025	£4,264	£3,988	£3,963	£3,768
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	13%	13%	14%	13%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(95)	(74)	(60)	(72)
2014 (showing effect of policy in 2013)	(96)	(68)	(60)	(73)
2017 (showing effect of policy in 2016)	(289)	(236)	(233)	(226)
2025	(290)	(237)	(234)	(227)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,112)	(832)	(775)	(698)
2014 (showing effect of policy in 2013)	(1,068)	(849)	(775)	(691)
2017 (showing effect of policy in 2016)	(1,994)	(1,677)	(1,981)	(1,491)
2025	(1,994)	(1,676)	(1,981)	(1,491)

OPTION 2a: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,325	£2,233	£3,327	£5,707
2014 (showing effect of policy in 2013)	£3,058	£2,010	£2,869	£5,526
2017 (showing effect of policy in 2016)	£19,421	£12,341	£12,037	£10,278
2025	£16,472	£10,790	£10,511	£8,884
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	8%
2014 (showing effect of policy in 2013)	4%	3%	4%	7%
2017 (showing effect of policy in 2016)	24%	17%	16%	14%
2025	21%	15%	14%	12%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO$_2$ saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,309	£6,613	£4,574	£6,391
2014 (showing effect of policy in 2013)	£6,271	£5,954	£3,960	£6,189
2017 (showing effect of policy in 2016)	£6,187	£5,413	£4,284	£4,328
2025	£5,252	£4,733	£3,738	£3,748
PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO$_2$ saved				
First	Micro Wind	EST Best	Large Wind	Gas CHP
Second	PV	PV	PV	–
Third	–	–	EST Best	–
Fourth	–	–	–	–
PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO$_2$ saved				
First	Micro Wind	EST Best	Large Wind	Gas CHP
Second	PV	PV	PV	–
Third	–	–	EST Best	–
Fourth	–	–	–	–

OPTION 2a: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	PV	Biomass CHP	Biomass CHP	Biomass CHP
Second	Biomass Comm	Carbon Permits	Large Wind	PV
Third	Micro Wind	PV	PV	Gas CHP
Fourth	EST Best	EST Best	EST Best	–
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	15%	13%	13%	14%
CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(123)	(187)
2014 (showing effect of policy in 2013)	(82)	(45)	(124)	(188)
2017 (showing effect of policy in 2016)	(349)	(133)	(253)	(134)
2025	(342)	(134)	(254)	(136)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(665)	(1,690)	(4,378)
2014 (showing effect of policy in 2013)	(741)	(658)	(1,652)	(4,378)
2017 (showing effect of policy in 2016)	(3,798)	£2,129	(1,346)	(3,859)
2025	(3,638)	£2,136	(1,344)	(3,890)

OPTION 2a: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,382	£3,465	£3,194	£3,160
2014 (showing effect of policy in 2013)	£3,820	£3,024	£2,739	£2,970
2017 (showing effect of policy in 2016)	£17,753	£12,866	£12,120	£9,925
2025	£15,387	£11,196	£10,397	£8,668
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	5%	5%	5%	4%
2014 (showing effect of policy in 2013)	4%	4%	4%	4%
2017 (showing effect of policy in 2016)	19%	18%	18%	13%
2025	16%	16%	16%	12%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£5,326	£4,787	£5,399	£4,801
2014 (showing effect of policy in 2013)	£4,669	£4,642	£4,617	£4,474
2017 (showing effect of policy in 2016)	£4,921	£4,588	£4,631	£4,353
2025	£4,265	£3,995	£3,973	£3,802
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	13%	13%	14%	13%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(129)	(116)	(102)	(135)
2014 (showing effect of policy in 2013)	(133)	(110)	(102)	(135)
2017 (showing effect of policy in 2016)	(293)	(236)	(235)	(240)
2025	(290)	(238)	(235)	(241)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,816)	(1,557)	(1,474)	(2,127)
2014 (showing effect of policy in 2013)	(1,712)	(1,574)	(1,474)	(2,122)
2017 (showing effect of policy in 2016)	(2,089)	(1,677)	(2,005)	(1,675)
2025	(1,994)	(1,692)	(2,005)	(1,671)

OPTION 3: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,322	£2,231	£3,062	£2,520
2014 (showing effect of policy in 2013)	£5,364	£3,661	£4,640	£3,857
2017 (showing effect of policy in 2016)	£4,627	£3,403	£4,019	£3,499
2025	£4,627	£3,403	£3,975	£3,499
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	3%
2014 (showing effect of policy in 2013)	7%	5%	6%	5%
2017 (showing effect of policy in 2016)	6%	5%	5%	5%
2025	6%	5%	5%	5%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,300	£6,608	£7,022	£6,887
2014 (showing effect of policy in 2013)	£5,671	£6,160	£5,855	£6,185
2017 (showing effect of policy in 2016)	£1,492	£1,492	£1,430	£1,492
2025	£1,492	£1,492	£1,414	£1,492

PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	PV	EST Best
Second	PV	PV	Medium Wind	PV
Third	–	–	EST Best	Biomass Comm
Fourth	–	–	–	EST Advanced

PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	PV	PV	PV
Second	PV	EST Best	Large Wind	EST Best
Third	–	–	Medium Wind	Biomass Comm
Fourth	–	–	EST Best	–

OPTION 3: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Carbon Permits	Carbon Permits	Carbon Permits	Carbon Permits
Second	–	–	Large Wind	–
Third	–	–	–	–
Fourth	–	–	–	–
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	0%	0%	1%	0%
CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(78)	(44)
2014 (showing effect of policy in 2013)	(152)	(86)	(156)	(82)
2017 (showing effect of policy in 2016)	£0	£0	(91)	£0
2025	£0	£0	(91)	£0
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(666)	(878)	(853)
2014 (showing effect of policy in 2013)	(1,276)	(1,144)	(1,670)	(1,237)
2017 (showing effect of policy in 2016)	£0	£0	(1,504)	£0
2025	£0	£0	(1,504)	£0

OPTION 3: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,149	£3,219	£2,942	£2,076
2014 (showing effect of policy in 2013)	£6,389	£4,774	£4,363	£3,394
2017 (showing effect of policy in 2016)	£5,212	£4,039	£3,776	£3,315
2025	£5,172	£4,003	£3,744	£3,293
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	4%	4%	4%	3%
2014 (showing effect of policy in 2013)	7%	7%	7%	5%
2017 (showing effect of policy in 2016)	6%	6%	6%	5%
2025	5%	6%	6%	4%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,907	£7,087	£7,769	£6,074
2014 (showing effect of policy in 2013)	£5,498	£6,214	£6,193	£5,711
2017 (showing effect of policy in 2016)	£1,448	£1,441	£1,443	£1,454
2025	£1,436	£1,429	£1,431	£1,444
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	1%	1%	1%	1%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(95)	(74)	(60)	(72)
2014 (showing effect of policy in 2013)	(185)	(123)	(113)	(154)
2017 (showing effect of policy in 2016)	(83)	(74)	(67)	(45)
2025	(83)	(74)	(67)	(45)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,112)	(832)	(775)	(698)
2014 (showing effect of policy in 2013)	(2,308)	(1,457)	(1,323)	(1,185)
2017 (showing effect of policy in 2016)	(1,379)	(1,224)	(1,107)	(747)
2025	(1,379)	(1,224)	(1,107)	(747)

OPTION 3a: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,325	£2,233	£3,327	£5,707
2014 (showing effect of policy in 2013)	£5,372	£3,667	£5,147	£5,545
2017 (showing effect of policy in 2016)	£4,627	£3,403	£4,018	£7,516
2025	£4,627	£3,403	£3,975	£7,080
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	8%
2014 (showing effect of policy in 2013)	7%	5%	7%	7%
2017 (showing effect of policy in 2016)	6%	5%	5%	10%
2025	6%	5%	5%	10%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,309	£6,613	£4,574	£6,391
2014 (showing effect of policy in 2013)	£5,679	£6,170	£5,014	£6,110
2017 (showing effect of policy in 2016)	£1,492	£1,492	£1,430	£3,202
2025	£1,492	£1,492	£1,414	£3,017
PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	Large Wind	Gas CHP
Second	PV	PV	PV	–
Third	–	–	EST Best	–
Fourth	–	–	–	–
PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	PV	PV	Gas CHP
Second	PV	EST Best	Large Wind	–
Third	–	–	Gas CHP	–
Fourth	–	–	EST Best	–

OPTION 3a: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Carbon Permits	Carbon Permits	Carbon Permits	Carbon Permits
Second	–	–	Large Wind	Gas CHP
Third	–	–	–	–
Fourth	–	–	–	–

LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	0%	0%	1%	6%

CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(123)	(187)
2014 (showing effect of policy in 2013)	(152)	(86)	(199)	(189)
2017 (showing effect of policy in 2016)	£0	£0	(91)	(190)
2025	£0	£0	(91)	(191)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				

NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(665)	(1,690)	(4,378)
2014 (showing effect of policy in 2013)	(1,276)	(1,143)	(2,557)	(4,406)
2017 (showing effect of policy in 2016)	£0	£0	(1,504)	(4,406)
2025	£0	£0	(1,504)	(4,406)

OPTION 3a: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,382	£3,465	£3,194	£3,160
2014 (showing effect of policy in 2013)	£6,431	£4,883	£5,710	£3,938
2017 (showing effect of policy in 2016)	£5,319	£4,064	£3,810	£4,454
2025	£5,267	£4,026	£3,774	£4,308
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	5%	5%	5%	4%
2014 (showing effect of policy in 2013)	7%	7%	9%	5%
2017 (showing effect of policy in 2016)	6%	6%	6%	6%
2025	6%	6%	6%	6%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£5,326	£4,787	£5,399	£4,801
2014 (showing effect of policy in 2013)	£5,493	£5,023	£5,553	£4,980
2017 (showing effect of policy in 2016)	£1,477	£1,450	£1,456	£1,954
2025	£1,463	£1,437	£1,442	£1,890
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	1%	1%	1%	3%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(129)	(116)	(102)	(135)
2014 (showing effect of policy in 2013)	(190)	(157)	(193)	(200)
2017 (showing effect of policy in 2016)	(88)	(75)	(68)	(99)
2025	(88)	(75)	(68)	(99)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,816)	(1,557)	(1,474)	(2,127)
2014 (showing effect of policy in 2013)	(2,392)	(2,036)	(3,111)	(2,406)
2017 (showing effect of policy in 2016)	(1,494)	(1,252)	(1,147)	(1,996)
2025	(1,494)	(1,252)	(1,147)	(1,996)

OPTION 4: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,322	£2,231	£3,062	£2,520
2014 (showing effect of policy in 2013)	£5,364	£3,661	£4,640	£3,857
2017 (showing effect of policy in 2016)	£10,347	£8,346	£9,352	£8,520
2025	£8,833	£7,073	£7,923	£7,224
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	3%
2014 (showing effect of policy in 2013)	7%	5%	6%	5%
2017 (showing effect of policy in 2016)	13%	11%	12%	11%
2025	11%	10%	10%	10%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,300	£6,608	£7,022	£6,887
2014 (showing effect of policy in 2013)	£5,671	£6,160	£5,855	£6,185
2017 (showing effect of policy in 2016)	£3,319	£3,661	£3,333	£3,640
2025	£2,836	£3,102	£2,824	£3,086
PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	PV	EST Best
Second	PV	PV	Medium Wind	PV
Third	–	–	EST Best	Biomass Comm
Fourth	–	–	–	EST Advanced
PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	PV	PV	PV
Second	PV	EST Best	Large Wind	EST Best
Third	–	–	Medium Wind	Biomass Comm
Fourth	–	–	EST Best	–

OPTION 4: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Carbon Permits	Carbon Permits	Carbon Permits	Carbon Permits
Second	EST Advanced	EST Advanced	EST Advanced	EST Advanced
Third	–	–	Large Wind	–
Fourth	–	–	–	–
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	15%	15%	15%	15%
CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(78)	(44)
2014 (showing effect of policy in 2013)	(152)	(86)	(156)	(82)
2017 (showing effect of policy in 2016)	(74)	(46)	(137)	(48)
2025	(74)	(46)	(138)	(48)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(666)	(878)	(853)
2014 (showing effect of policy in 2013)	(1,276)	(1,144)	(1,670)	(1,237)
2017 (showing effect of policy in 2016)	(376)	£166	(1,372)	£121
2025	(376)	£166	(1,372)	£121

OPTION 4: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,149	£3,219	£2,942	£2,076
2014 (showing effect of policy in 2013)	£6,389	£4,774	£4,363	£3,394
2017 (showing effect of policy in 2016)	£12,379	£8,382	£8,525	£8,274
2025	£10,447	£7,186	£7,277	£6,983
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	4%	4%	4%	3%
2014 (showing effect of policy in 2013)	7%	7%	7%	5%
2017 (showing effect of policy in 2016)	13%	12%	13%	11%
2025	11%	10%	11%	9%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,907	£7,087	£7,769	£6,074
2014 (showing effect of policy in 2013)	£5,498	£6,214	£6,193	£5,711
2017 (showing effect of policy in 2016)	£3,438	£2,991	£3,257	£3,629
2025	£2,901	£2,565	£2,781	£3,063
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	16%	14%	15%	16%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(95)	(74)	(60)	(72)
2014 (showing effect of policy in 2013)	(185)	(123)	(113)	(154)
2017 (showing effect of policy in 2016)	(165)	(126)	(103)	(83)
2025	(165)	(126)	(103)	(83)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,112)	(832)	(775)	(698)
2014 (showing effect of policy in 2013)	(2,308)	(1,457)	(1,323)	(1,185)
2017 (showing effect of policy in 2016)	(1,978)	(1,169)	(705)	(440)
2025	(1,978)	(1,169)	(705)	(440)

OPTION 4a: BASE CASE – Report Unit by Scenario				
CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,325	£2,233	£3,327	£5,707
2014 (showing effect of policy in 2013)	£5,372	£3,667	£5,147	£5,545
2017 (showing effect of policy in 2016)	£10,539	£8,507	£9,528	£11,162
2025	£8,833	£7,073	£7,923	£9,432
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	8%
2014 (showing effect of policy in 2013)	7%	5%	7%	7%
2017 (showing effect of policy in 2016)	13%	12%	12%	15%
2025	11%	10%	10%	13%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,309	£6,613	£4,574	£6,391
2014 (showing effect of policy in 2013)	£5,679	£6,170	£5,014	£6,110
2017 (showing effect of policy in 2016)	£3,380	£3,731	£3,396	£4,767
2025	£2,836	£3,103	£2,824	£4,028
PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	Large Wind	Gas CHP
Second	PV	PV	PV	–
Third	–	–	EST Best	–
Fourth	–	–	–	–
PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	PV	PV	Gas CHP
Second	PV	EST Best	Large Wind	–
Third	–	–	Gas CHP	–
Fourth	–	–	EST Best	–

OPTION 4a: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Carbon Permits	Carbon Permits	Carbon Permits	Carbon Permits
Second	EST Advanced	EST Advanced	EST Advanced	Gas CHP
Third	–	–	Large Wind	EST Advanced
Fourth	–	–	–	–

LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	16%	17%	17%	15%

CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(123)	(187)
2014 (showing effect of policy in 2013)	(152)	(86)	(199)	(189)
2017 (showing effect of policy in 2016)	(74)	(46)	(137)	(166)
2025	(74)	(46)	(138)	(167)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				

NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(665)	(1,690)	(4,378)
2014 (showing effect of policy in 2013)	(1,276)	(1,143)	(2,557)	(4,406)
2017 (showing effect of policy in 2016)	(376)	£166	(1,372)	(3,022)
2025	(376)	£166	(1,372)	(3,022)

OPTION 4a: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,382	£3,465	£3,194	£3,160
2014 (showing effect of policy in 2013)	£6,431	£4,883	£5,710	£3,938
2017 (showing effect of policy in 2016)	£12,678	£8,544	£8,700	£9,143
2025	£10,500	£7,200	£7,296	£7,614
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	5%	5%	5%	4%
2014 (showing effect of policy in 2013)	7%	7%	9%	5%
2017 (showing effect of policy in 2016)	13%	12%	13%	12%
2025	11%	10%	11%	10%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£5,326	£4,787	£5,399	£4,801
2014 (showing effect of policy in 2013)	£5,493	£5,023	£5,553	£4,980
2017 (showing effect of policy in 2016)	£3,521	£3,049	£3,324	£4,010
2025	£2,916	£2,569	£2,788	£3,340
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	17%	16%	16%	17%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(129)	(116)	(102)	(135)
2014 (showing effect of policy in 2013)	(190)	(157)	(193)	(200)
2017 (showing effect of policy in 2016)	(168)	(126)	(104)	(117)
2025	(168)	(126)	(104)	(117)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,816)	(1,557)	(1,474)	(2,127)
2014 (showing effect of policy in 2013)	(2,392)	(2,036)	(3,111)	(2,406)
2017 (showing effect of policy in 2016)	(2,051)	(1,188)	(731)	(1,341)
2025	(2,051)	(1,188)	(731)	(1,341)

OPTION 5: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,322	£2,231	£3,062	£2,520
2014 (showing effect of policy in 2013)	£5,364	£3,661	£4,640	£3,857
2017 (showing effect of policy in 2016)	£21,445	£14,850	£16,327	£14,057
2025	£17,591	£12,278	£13,291	£11,430
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	3%
2014 (showing effect of policy in 2013)	7%	5%	6%	5%
2017 (showing effect of policy in 2016)	27%	20%	21%	19%
2025	22%	17%	17%	15%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,300	£6,608	£7,022	£6,887
2014 (showing effect of policy in 2013)	£5,671	£6,160	£5,855	£6,185
2017 (showing effect of policy in 2016)	£6,882	£6,514	£5,805	£5,991
2025	£5,647	£5,385	£4,727	£4,873

PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	PV	EST Best
Second	PV	PV	Medium Wind	PV
Third	–	–	EST Best	Biomass Comm
Fourth	–	–	–	EST Advanced

PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	PV	PV	PV
Second	PV	EST Best	Large Wind	EST Best
Third	–	–	Medium Wind	Biomass Comm
Fourth	–	–	EST Best	–

OPTION 5: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	PV	Carbon Permits	Biomass CHP	Biomass CHP
Second	Biomass Comm	Biomass CHP	PV	PV
Third	Micro Wind	PV	EST Advanced	EST Advanced
Fourth	EST Advanced	EST Advanced	Large Wind	Carbon Permits
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	18%	17%	19%	19%
CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(78)	(44)
2014 (showing effect of policy in 2013)	(152)	(86)	(156)	(82)
2017 (showing effect of policy in 2016)	(384)	(155)	(330)	(180)
2025	(385)	(155)	(331)	(181)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(666)	(878)	(853)
2014 (showing effect of policy in 2013)	(1,276)	(1,144)	(1,670)	(1,237)
2017 (showing effect of policy in 2016)	(3,401)	£1,655	(1,468)	(3,048)
2025	(3,401)	£1,655	(1,468)	(3,048)

OPTION 5: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,149	£3,219	£2,942	£2,076
2014 (showing effect of policy in 2013)	£6,389	£4,774	£4,363	£3,394
2017 (showing effect of policy in 2016)	£22,438	£15,991	£16,011	£13,489
2025	£18,284	£13,041	£13,019	£11,041
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	4%	4%	4%	3%
2014 (showing effect of policy in 2013)	7%	7%	7%	5%
2017 (showing effect of policy in 2016)	24%	22%	24%	18%
2025	19%	18%	20%	15%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,907	£7,087	£7,769	£6,074
2014 (showing effect of policy in 2013)	£5,498	£6,214	£6,193	£5,711
2017 (showing effect of policy in 2016)	£6,232	£5,707	£6,118	£5,916
2025	£5,078	£4,654	£4,975	£4,843
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	19%	18%	19%	18%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(95)	(74)	(60)	(72)
2014 (showing effect of policy in 2013)	(185)	(123)	(113)	(154)
2017 (showing effect of policy in 2016)	(388)	(308)	(285)	(293)
2025	(389)	(309)	(286)	(294)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,112)	(832)	(775)	(698)
2014 (showing effect of policy in 2013)	(2,308)	(1,457)	(1,323)	(1,185)
2017 (showing effect of policy in 2016)	(2,953)	(1,885)	(1,554)	(1,098)
2025	(2,953)	(1,885)	(1,554)	(1,098)

OPTION 5a: BASE CASE – Report Unit by Scenario

CONSTRUCTION COSTS	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
AVERAGE UNIT COSTS (£ per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£3,325	£2,233	£3,327	£5,707
2014 (showing effect of policy in 2013)	£5,372	£3,667	£5,147	£5,545
2017 (showing effect of policy in 2016)	£21,662	£15,021	£16,516	£14,231
2025	£17,596	£12,280	£13,294	£11,488
% INCREASE IN AVERAGE UNIT COSTS (over Part L):				
2011 (showing effect of policy in 2010)	4%	3%	4%	8%
2014 (showing effect of policy in 2013)	7%	5%	7%	7%
2017 (showing effect of policy in 2016)	27%	20%	22%	19%
2025	22%	17%	17%	15%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£6,309	£6,613	£4,574	£6,391
2014 (showing effect of policy in 2013)	£5,679	£6,170	£5,014	£6,110
2017 (showing effect of policy in 2016)	£6,952	£6,589	£5,872	£6,066
2025	£5,649	£5,386	£4,728	£4,895

PROJECTED TECHNOLOGY MIX (in 2011 (showing effect of policy in 2010))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	EST Best	Large Wind	Gas CHP
Second	PV	PV	PV	–
Third	–	–	ESTBest	–
Fourth	–	–	–	–

PROJECTED TECHNOLOGY MIX (in 2014 (showing effect of policy in 2013))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	Micro Wind	PV	PV	Gas CHP
Second	PV	EST Best	Large Wind	–
Third	–	–	Gas CHP	–
Fourth	–	–	EST Best	–

OPTION 5a: BASE CASE – Report Unit by Scenario *(continued)*

PROJECTED TECHNOLOGY MIX (in 2017 (showing effect of policy in 2016))	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
Ordered on basis of tonnes of CO_2 saved				
First	PV	Carbon Permits	Biomass CHP	Biomass CHP
Second	Biomass Comm	Biomass CHP	PV	PV
Third	Micro Wind	PV	EST Advanced	EST Advanced
Fourth	EST Advanced	EST Advanced	Large Wind	Carbon Permits

LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	19%	18%	20%	19%

CHANGE IN ENERGY COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(90)	(45)	(123)	(187)
2014 (showing effect of policy in 2013)	(152)	(86)	(199)	(189)
2017 (showing effect of policy in 2016)	(384)	(155)	(330)	(180)
2025	(385)	(155)	(331)	(184)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				

NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Small Developments**	**City Infill Developments**	**Market Town Developments**	**Urban Regeneration Developments**
2011 (showing effect of policy in 2010)	(720)	(665)	(1,690)	(4,378)
2014 (showing effect of policy in 2013)	(1,276)	(1,143)	(2,557)	(4,406)
2017 (showing effect of policy in 2016)	(3,401)	£1,655	(1,468)	(3,048)
2025	(3,401)	£1,655	(1,468)	(3,124)

OPTION 5a: BASE CASE – Report Unit by Dwelling Type

CONSTRUCTION COSTS	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
AVERAGE UNIT COSTS (£ per dwelling over Part L 2006):				
2011 (showing effect of policy in 2010)	£4,382	£3,465	£3,194	£3,160
2014 (showing effect of policy in 2013)	£6,431	£4,883	£5,710	£3,938
2017 (showing effect of policy in 2016)	£22,698	£16,155	£16,182	£13,659
2025	£18,288	£13,055	£13,038	£11,043
% INCREASE IN AVERAGE UNIT COSTS (over Part L 2006):				
2011 (showing effect of policy in 2010)	5%	5%	5%	4%
2014 (showing effect of policy in 2013)	7%	7%	9%	5%
2017 (showing effect of policy in 2016)	24%	22%	25%	19%
2025	19%	18%	20%	15%
AVERAGE COST OF CARBON SAVINGS (£ per tonne CO_2 saved per dwelling over Part L):				
2011 (showing effect of policy in 2010)	£5,326	£4,787	£5,399	£4,801
2014 (showing effect of policy in 2013)	£5,493	£5,023	£5,553	£4,980
2017 (showing effect of policy in 2016)	£6,304	£5,765	£6,183	£5,991
2025	£5,079	£4,659	£4,982	£4,843
LEARNING RATES				
OVERALL EFFECT: % cost reduction due to effect of Learning Rates on the total annual construction costs; between 2017 and 2025	19%	19%	19%	19%
CHANGE IN ENERGY COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(129)	(116)	(102)	(135)
2014 (showing effect of policy in 2013)	(190)	(157)	(193)	(200)
2017 (showing effect of policy in 2016)	(388)	(308)	(285)	(293)
2025	(389)	(309)	(287)	(294)
NB: The proportion of this net change that will be realised by occupants is dependent upon the delivery strategy employed				
NPV OF CHANGE IN OVERALL OPERATIONAL COSTS £	**Detached Houses**	**End Terraces**	**Mid Terraces**	**Flats**
2011 (showing effect of policy in 2010)	(1,816)	(1,557)	(1,474)	(2,127)
2014 (showing effect of policy in 2013)	(2,392)	(2,036)	(3,111)	(2,406)
2017 (showing effect of policy in 2016)	(2,953)	(1,885)	(1,554)	(1,098)
2025	(2,953)	(1,899)	(1,574)	(1,098)

ISBN 978-1-4098-0443-7

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ISBN: 978-1-4098-0443-7