Environmental Change Institute
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Reducing the environmental impact of housing

Final Report

Consultancy study in support of the Royal Commission on Environmental Pollution's 26th Report on the Urban Environment

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Literature review

- The findings of the various research reports considered in the literature review are highly dependent on the underlying assumptions and the objectives and agenda of the organisation responsible. This needs to be borne in mind when attempting to use the results
- There is consensus amongst recent research reports that the technologies required to achieve major reductions in carbon emissions are available and have the potential to deliver
- Detailed partial studies are useful and beneficial but may miss some of the crucial interactions eg demolition has implications for energy, waste and land-use, and impacts on the density and location of new housing
- Savings are generally expressed in terms of technology and money rather than the wider benefits or dis-benefits to society
- Cost estimates are inherently difficult since they are so dependent on the underlying assumptions which can change drastically over, say, a 50 year time period. Therefore current cost-effectiveness is not a reliable indication of future cost-effectiveness – it is dangerous to place too much emphasis on this aspect when looking over longer timeframes since the underlying costs and assumptions will change over time
- Estimates of savings tend to be technology focused because these are easier to quantify and more amenable to policy intervention than social factors. Such estimates define a range of savings upon which societal factors may have more or less influence
- There is greater agreement between the reports in terms of the technological potential (eg in water and energy sectors) than between estimates of savings from social or behavioural measures (eg in waste sector), highlighting the difficulties and uncertainties around the latter
- Despite research that indicates many of the savings are currently cost-effective, these savings are not being achieved in practice, indicating that the economically-rational consumer model is flawed and there is a lack of compensating policy
- Significant societal and behavioural change, leading to greater resource consciousness and reduced consumption on all levels, is expected to result in higher savings than those possible through technological change alone
- Explicit acknowledgement of socio-technical systems, the two-way interplay between society and technology, is lacking from the research reports covered in the literature review, although some aspects are inherent in the assumptions made
- The failure to fully address the socio-technical context may be one reason why the savings identified in various research reports are not being achieved in practice, emphasising the need for an holistic approach

Housing

- By 2050, the housing stock will turn over once in every 1900 years if demolition continues at current levels (around 17,000 dwellings per annum)
- The housing sector is a difficult area in which to bring about change because the buildings themselves are long-lasting and expensive, embodying cultural and technological aspects which determine patterns of production and consumption
- The focus must be on new housing and refurbishment of the existing stock – both have a crucial role to play in achieving the 60% carbon reductions target. Over 85% of existing dwellings are likely to still be standing in 2050, representing around 70% of the 2050 stock, and an additional 6.8 million new dwellings will need to be built to meet projected population growth
- The key actors involved in new build and refurbishment of existing housing are different – policy needs to be targeted appropriately

- Both new build and demolition rates need to be increased over and above current levels to address the current under-supply of housing, remove the most inefficient properties from the housing stock and minimise greenfield take through increased density
- A demolition strategy requires a clear prioritisation of objectives (eg eradication of fuel poverty, minimising greenfield take) and a co-ordinated plan to deal with the associated consequences eg increase in waste arisings
- The planning system plays a key role in ensuring greater sustainability of housing and has the potential to address the full range of impacts: energy, water land-use and waste eg Merton's Local Development Framework
- Tighter building standards are essential for new build if the environmental impact of housing is to be reduced. These need to encompass the full range of impacts – energy, water and waste (both household and construction & demolition waste). Building regulations need to be properly enforced
- There is a significant skills shortage in the construction and planning industry in terms of delivering more sustainable housing and ensuring compliance with Building Regulations
- Sustainable housing brings many benefits to the occupier – improved comfort, increased service, lower costs and better quality of life

Energy and carbon

- The energy sector appears to be the area in which the most detailed research has been undertaken in comparison to the other impacts, which has enabled a clearer policy focus. However, reductions in energy or carbon have been outweighed by increasing household numbers and demands for energy services, with carbon emissions from housing rising 10% in the last decade, even with a range of policies in place to reduce emissions
- Carbon emissions vary under the three scenarios modelled. In Scenario A (current policies and technologies continued into the future, with incremental change in standards and regulations in line with current trends), emissions continue to rise and do not fall below 1996 levels for another three decades. In Scenario B, emissions in 2050 fall to 44% of those in 1996. In Scenario C, emissions in 2050 fall to 25% of 1996 levels
- In all three scenarios it is assumed that there is no dramatic shift in the carbon content of electricity supplied by the national grid. The model and report focus on reducing energy demand within homes and decentralised local energy generation
- A combination of approaches eg refurbishment, demolition, energy-efficiency, building-integrated Combine Heat and Power and renewables, is necessary to deliver low-carbon housing, framed within a clear and co-ordinated strategy, with responsibility at a Local Authority level. There are important regional considerations in terms of the associated environmental impacts eg water, availability of energy sources (especially renewables), land availability, landfill resources
- If no action was taken on the housing stock, total decarbonisation of electricity supplied from the grid would not be sufficient to achieve a 60% reduction in carbon emissions and would not even result in a halving of carbon emissions
- The emphasis must be on demand reduction first, as the least cost strategy, followed by considerable installation of LZC, so that the subsequent demand has a minimal carbon impact. Even if the LZC are not installed, the demand on centralised supply is minimised
- Significant refurbishment of the existing stock is a key factor in reducing overall emissions, with existing houses brought to a level beyond current Building Regulations. Currently programmes are piecemeal and need to focus on whole-house refurbishment

- Point of sale or rental is a target for fiscal incentives, eg stamp duty rebates, to encourage investment in the energy-efficiency of the housing stock. Fiscal incentives should be launched alongside the Home Information Pack
- Although Ecohomes ‘excellent’ rating is seen as a challenging standard by the mainstream construction industry, it is still way below the standard required of new build if a 60% reduction in carbon emissions is to be attained. New buildings must be constructed to ultra-low energy standards (eg BedZED or Passive House standards), with Building Regulations set to achieve zero carbon emissions (for space heating) by 2020 at the latest. It would be helpful if standards for 2010, 2015 and 2020 were published now, to give industry a clear signal of the direction in which they need to innovate
- There needs to be a move towards standards based on monitored performance and energy in use
- Communal energy solutions and distributed generation can deliver carbon savings but require appropriate policy to support the development of new infrastructure eg district heating networks
- Combined Heat and Power and renewables integrated into buildings provides 30-85% of heat, and 23-100% of electricity in the different scenarios. The appropriate technology depends on house type and fuel availability: communal systems are appropriate for dense housing, micro-CHP is appropriate for suburban areas, and biomass and heat pumps appropriate where there is no gas network. Roof based technologies (PV, solar thermal and micro-wind) can make a contribution throughout the housing stock
- High uptake of Combined Heat and Power and renewables by 2050 could imply significant commercial opportunity for Energy Services Companies (ESCos), particularly in social housing and in new build
- The high level of LZC uptake under Scenarios B & C requires major changes over a relatively short timescale for both new build and refurbishment and therefore needs appropriate policy support
- Significant savings can be made in lights and appliances, but this depends on EU level action, supported by national governments. The EU has been slower than other jurisdictions to make use of mandatory standards. New technologies need introduction to market including Vacuum Insulated Panels (eg for refrigeration) and Light Emitting Diode (LED) lighting
- There is also a risk of significant increases in ownership (eg of cooling appliances) that could increase energy consumption
- Estimates for the embodied energy of new build and refurbished dwellings vary widely, but in all cases the embodied energy implied is significantly outweighed by the potential for savings from energy in use (assuming a 60 year lifespan as a minimum) provided the refurbished or replacement dwelling is delivered to an extremely high standard

Land-use

- Building at higher densities minimises the land required and associated environmental impact and can thus reduce greenfield take
- Building within, and densification of, existing developments makes use of the established infrastructure and therefore requires less land and resources than new developments on greenfield land
- Appropriately sized smaller dwellings (in terms of m^2) can help achieve higher densities and are more appropriate to the UK’s ageing population
- Good design and planning are essential to create high density developments which promote both a good quality of life and resource efficiency

Waste

- Improved data collection and monitoring in the waste sector, particularly in relation to construction and demolition, is crucial to identifying and delivering the necessary reductions
- The necessary increase in housing renewal, both through demolition and refurbishment, will result in a significant increase in construction and demolition waste, exceeding current landfill capacity. Appropriate waste management strategies are required to reduce overall waste production and increase re-use and recycling, thereby minimising the volume sent to landfill
- Increased recycling and re-use of construction materials has the double environmental benefit of reducing waste arisings and minimising resource consumption
- New dwellings need to be built with end-of-life deconstruction as part of the design brief to support the deployment of materials and methods amenable to re-use
- In relation to household waste, the emphasis tends to be on increasing recycling and composting, as opposed to reducing waste production overall. There is heavy reliance on behavioural measures in this sector rather than technological fixes

Water

- In the water sector, significant savings are possible at little or no cost premium and which require minimal behavioural change
- Detailed modelling of water consumption within the UK housing stock would help quantify the level of savings available in both existing and new build dwellings
- The water sector shares many parallels with the energy sector, with historically too much focus on new supply and too little on reducing demand. There is also an interplay between energy use and hot water
- Water has a strong regional aspect, being in particularly short supply where housing demand is highest
- Water demand management must be incorporated into the planning system to ensure that appropriate measures are included before planning permission is granted. In severe cases, lack of water resources should be a reason for planning refusal

Society

- Predictions of environmental benefits can fail to materialise as a result of unexpected behaviour and societal factors eg conservatories have the potential to reduce space heating demand (through solar gain) if unheated but heating of conservatories has resulted in the trend being in the opposite direction and created a significant new energy demand
- Behavioural change is more likely to occur if it is made easy – the provision of segregated bins and doorstep recycling services has made it easier for people to recycle – imparting ‘agency’ – and so recycling rates have increased
- A fundamental shift in the established socio-technical context could help ensure the necessary transformation of society, supported by an over-arching framework such as personal carbon trading
- A more in-depth exploration of how society and technology might interact to bring about the necessary savings, with a strong emphasis on practical policy measures, would be beneficial in developing an appropriate and effective framework for delivery
- Subtle indirect approaches, such as an emphasis on local community and employment, could engender more sustainable attitudes and behaviours

Policy

- Doing nothing is not an option – continuation of current trajectories will only be sufficient to achieve minimal reductions in carbon, let alone the 60% target
- Detailed modelling of trajectories over a long timescale is essential in identifying the speed with which technology should be developed and the appropriate policy framework
- The full range of energy efficiency policies, such as grants, incentives, minimum standards, have been shown to work in delivering savings at a low cost for the net benefits, but have not been used to full effect. There has also been insufficient emphasis on reducing consumption (or even ownership of some products) to date
- Action needs to be taken immediately to meet the targets in 2050 due to inertia in the system eg because of the time taken to agree policy, slow stock turnover rates (appliances replaced every 15 years, roofs every 100 years and houses several hundred years). Standards need to be increased rapidly rather than ramped up slowly to ensure that maximum savings are achieved as soon as possible
- Future standards need to be set now, perhaps over several rounds, so that clear signals are given. There is a need to review whether the voluntary approach rather than a mandatory standard has served society well
- Policy-makers are responsible for creating a framework for sufficiency to ensure the evolution of society and technology along a more sustainable pathway rather than continuing to allow society and technology to evolve freely in potentially consumptive directions
- Policy must recognise the potentially opposing trends within society which may work against reducing consumption and sufficiency eg increasing size of appliances and increasing appliance ownership, and be proactive in mitigating such trends
- An holistic approach is essential to provide an appreciation of the full range of interactions, eg the links between demolition rate, energy, waste and land-use, and therefore provide clarity on the appropriate objectives and how to prioritise these, along with an acknowledgement of the trade-offs involved
- Bringing about socio-technical change towards greater sustainability requires an appropriate mix of policies, such as recommended standards, grants and incentives, to encourage transformation of society
- Change needs to take place at a number of different scales, with local and regional authorities playing a key role in developing change and innovation in small niches within a strong regulatory and policy framework at the national and European level
- More perceptive schemes are required that recognise the role energy services play in people's lives and not based on arguments appealing to technical determinism or economic rationality
- Strong product policy at both a European and national level is vital in bringing efficient products to market in preparation for higher prices, eg fuel price rises or taxation, – the products and systems have to be available to enable people to take action towards reducing consumption as a result of higher prices
- Public procurement (especially of social housing) can create new markets through the application of tough standards for all developments (part-)funded though the public money
- The various building standards (Building Regulations, Ecohomes, Code for Sustainable Buildings) need to be brought together in a single chain of guidance which incorporates the full range of environmental impacts and made more stringent
- There is a debate as to whether energy is kept 'invisible' by implementing supply-side measures eg more nuclear power, or whether to make it more visible by moving towards decentralised power generation, requiring greater engagement and participation by individuals and potentially leading to more resource-conscious behaviour, with implications for metering, monitoring, energy bills and personal carbon trading

1. Introduction

1.1. Scope of the study

The Royal Commission on Environmental Pollution launched its study on the urban environment in October 2003, identifying four priority themes: sustainable urban transport, sustainable urban management (Local Agenda 21, EMAS, indicators), sustainable urban construction (resource and energy efficiency, demolition waste, design issues) and sustainable urban design (land use-regeneration, brown field sites, urban sprawl, land use densities).

This study on reducing the environmental impact of housing forms part of the wider review, with a remit to assist the Commission with the production of its 26th Report on the Urban Environment by:

a) completing a literature review to synthesise and critically appraise information on the scope for the UK's housing stock to be built and/or refurbished to higher environmental standards, taking account of the wide social context
b) modelling the environmental impact of a range of future housing projections

Housing is a complex area which cuts across all four of the priority themes and incorporates a variety of disciplines and issues, including architecture, planning, design, technology, behaviour, economics, social science, and construction techniques. The associated environmental impacts of housing are far-reaching and long lasting, ranging from the resources used to build the house (materials, water, energy, transport) and the waste produced during construction through to the resources used and waste produced by occupants of the house over its lifetime and finally, the waste and resources involved with demolition. Additionally there are the associated impacts arising from the wider infrastructure including transport, parking, drainage and provision of services, all of which make up the urban environment.

Given the limited time and resources available to this study, it was not possible to cover the full range of impacts. It was necessary to take a fairly narrow focus and, as such, this report provides a framework for consideration of the key issues. The main focus is of this report is energy, as this is the ECI's main area of expertise, but also encompasses the issues of land use, waste production and water. Wider planning issues and the transport sector are not covered in detail. Further information on the context of this study is provided in Appendix A.

In recent years there has been a growing number of reports that claim significant environmental savings could be made within the UK housing stock. However, many of these savings do not appear to be realised in practice and the Commission was interested to know the reasons behind this apparent mis-match between theory and reality. The literature review involves a critical overview and comparison of six recent research reports, looking at areas of consensus and disagreement to provide a realistic assessment of the potential savings available, with a particular focus on the models of socio-technical change assumed.

Alongside the literature review, modelling work was undertaken to assess the impacts of current and future housing in terms of energy use, carbon emissions, land use and waste production. The basis for this analysis was a detailed 'bottom-up' energy model, developed as part of the ECI's Building Market Transformation[1], (BMT) project, which links in with the modelling of land use and waste. For waste there are two main waste

[1] Building Market Transformation is a four year study funded by EPSRC and Carbon Trust and is part of a suite of projects under the Carbon Vision Programme, www.eci.ox.ac.uk/bmt

streams of relevance to this study: construction and demolition waste and household waste. For modelling purposes, the focus was on construction and demolition waste, however the literature review covers both waste streams.

Trajectories to 2050 were modelled for all three impacts under three scenarios:

1. Scenario A – assumes the broad continuation of current policies and incremental change of technologies
2. Scenario B – describes a 60% reduction in carbon emissions from housing
3. Scenario C – represents an extreme change, with further reductions in carbon emissions beyond 60%

The model outputs provide a framework for a discussion of what actions need to be taken and by whom in order to achieve the necessary savings.

1.2. Socio-technical systems

One of the key questions asked by the RCEP in the briefing for this study was ‘whether advocates of change are working with the right models of socio-technical systems in order to effectively promote environmental efficiency’. The social-technical interface is important because there is a tendency to view social and technical issues as distinct, when in reality they are closely interconnected. The aim of a socio-technical approach is to think more holistically about social and technical issues. This section provides a brief introduction to some of the underlying theory of socio-technical systems and the relevance to the housing sector. More detail is provided in Appendix B.

1.2.1. What are socio-technical systems?

Socio-technical systems are sectors or technical systems where the social and technical elements are strongly interconnected, such that it forms a coherent system. Examples are diverse and include utility systems (water, electricity, wastewater), transport systems, telecommunications and housing. The essential idea of the socio-technical systems literature is that technical systems are “both socially constructed and society shaping” (Hughes, 1987: 51), and hence technology and society need to be analysed in conjunction taking a broader sector-wide approach. As well as influencing existing technologies, society provides the context for developing new technologies and products: what innovation is needed, how it is developed in organisations, how it is influenced by policy makers and how is it taken up by society.

A key feature of socio-technical systems is that they are largely invisible, or rather, they are such an integral feature of modern life that their role can be overlooked (Graham and Marvin, 2001; Hinchliffe, 1996). Socio-technical system relations become increasingly stable over time as they are embedded within physical infrastructures, social norms, habits and institutions. Existing socio-technical systems begin to dictate the pattern and speed of future system change.

‘Innovation niches’ are seen as the key mechanism for bringing about radical change in socio-technical systems (Kemp, 1994; Kemp *et al.*, 1998; Schot *et al.*, 1994; Smith, 2004; Szejnwald Brown *et al.*, 2003; Unruh, 2002) and are most likely to be catalysed by a problem external to the socio-technical system, such as climate change in the case of housing. Innovation niches are small pockets of experimentation and innovation. However, the precise mechanisms by which niches grow to become new socio-technical systems are not well theorised (Smith, 2002). Governments can and should play a role, but the involvement of other types of organisation, including businesses, is essential for long-term fundamental change.

The relationship between materials/technologies and society is judged to be particularly strong in sectors where the physical infrastructure is durable and capital and technology intensive: this applies to housing, whereby the material features of housing are recognised as influencing the process of change, as well as other associated areas like energy, water and transport. In such sectors, contemporary policy making is heavily influenced by historical infrastructure decisions, as Shove suggests with reference to energy policy making:

"The grids of wires and pipes that permit energy flows… reveal patterns of past actions and priorities… These embodied practices and histories do not prohibit change, but they do make a difference to the scope, scale and form of contemporary decision making and to the character and location of energy policy making."
(Shove *et al* 1998:226).

Further ideas about change in the housing sector raised by adopting a socio-technical approach include:

- Housing material infrastructure is ubiquitous and plays a vital role in everyday life: it is 'black-boxed'[2], which helps explain why the ways in which it is provided and the way in which people interact with it as householders are rarely critically examined;
- The role of the built environment in slowing, or in some cases speeding up, the pace of change. Existing (energy inefficient) housing comprises the majority of the UK housing stock and presents a major difficulty for the Government in trying to reduce household energy consumption and carbon emissions. Hence the housing infrastructure is slowing down the pace of policy change. There are other instances in which infrastructure offers significant opportunities to catalyse shifts in policy, for example substantial new housing developments under the Sustainable Communities Plan;
- Recognition that most examples of environmental innovation in the housing sector have taken place within innovation niches (ie one-off housing developments or pockets of innovation), rather than through sector-wide shifts;
- Social networks and personal values have been an important influence on those who have successfully built or refurbished environmental housing, thereby revealing how change is not just about technology – it is a socio-technical process. In other areas, social networks and values may detract from positive environmental change eg housing developers prioritising profit over sustainability;
- It provides a basis for understanding why technology-centred policies aimed at reducing the environmental impact of housing have tended to be less successful than planned. It is because of a bias in policy towards concentrating on tangible technologies at the expense of social and behavioural issues.

[2] 'Black boxing' is defined by Rip and Kemp as using (technical) artefacts "without an indication of their history and inner working" (1998: 329).

2. Literature review

The objective of the literature review is to provide an overview of the likely benefits of making environmental improvements to old and new houses and the scale of the costs, based on recent research available. In particular, the aim was to draw out:

- Key messages and areas where there is consensus across reports;
- Areas where there are significant differences and the reasons for these;
- The extent to which environmental measures have been implemented, the reasons for their success or failure and the prospects for the future.

There are a number of recently published key research reports which address the environmental impact of housing from a variety of perspectives. A full range of reports were considered initially but since the time available to this study was limited, the decision was made to focus on six reports in detail which, between them, covered the range of environmental impacts (energy, water, land-use and waste) and addressed both existing buildings and new build. The aim was to select the most recent, relevant and substantive studies that provided credible quantified information, although obviously each study has its own limitations. The literature review focused on evaluating the various findings and recommendations of the each of the six reports and is not intended as a critique of the individual studies. Other reports were used to inform the wider context of the study as well as specific areas where appropriate.

The six reports selected were:

1. Bioregional: James N & Desai P (2003) *One planet living in the Thames Gateway*. Bioregional Development Group, London, UK.
2. BRE: Shorrock L, Henderson J and Utley J (2005) *Reducing carbon emissions from the UK housing stock.* Building Research Establishment, Watford, UK.
3. EA: Horton B (2005) *Sustainable Homes – the financial and environmental benefits.* Environment Agency, Bristol, UK.
4. ECI: Boardman B, Darby S, Killip G, Hinnells M, Jardine C, Palmer J & Sinden G (2005) *40% House.* Environmental Change Institute, University of Oxford, UK.
5. Entec: Entec, Richard Hodkinson Consultancy & eftec (2004) *Study into the environmental impacts of increasing the supply of housing in the UK*. Report to Defra, Entec UK Ltd, Leamington Spa, UK.
6. SDC: Sustainable Development Commission (2005a) *Sustainable buildings – the challenge of the existing stock.* SDC, London, UK.

Each report differs slightly in coverage and approach. These differences are summarised in Table 1 and a brief description of the coverage of each report is provided in Table 2. Some of the reports cover a wider range of issues than those identified in Table 1 – for instance, the Bioregional report looks at the environmental impact associated with food and transport. Whilst these are important areas to address, they are outside the remit of this current study and so have not been included for the purposes of this analysis. Since the main focus of this report is on energy, the full details of the literature review on energy are presented here. The detail on the remaining impacts (land-use, waste and water) is included in Appendix C.

Table 1 Coverage of research reports reviewed

	Timeline	Existing stock	New build	Energy	CO_2	Water	Waste	Land-use	Costs/ Economics	Social/ behavioural	Scenarios
Bioregional	static	-	✓	✓	✓	✓	✓	✓	✓	(✓)[a]	✓
BRE	2000-2050	✓	✓	✓	✓	-	-	-	✓	-	✓
EA	static	-	✓	✓	-	✓	✓	-	✓	-	-
ECI	1996-2050	✓	✓	✓	✓	-	-	-	-	(✓)[a]	✓
Entec	2001-2016	-	✓	-	✓	✓	✓	✓	✓	-	✓
SDC	static	✓	-	✓	✓	✓	✓	-	(✓)[a]	(✓)[a]	-

a – limited

Table 2 Summary of report coverage

	Brief overview
Bioregional	*Focuses on the Thames Gateway as a case study to investigate the implications of building 200,000 new homes to different standards. Detailed calculation of carbon emissions, ecological footprint and costs under four scenarios for a range of impacts: energy, transport, infrastructure, waste, water, built land, services and food.*
BRE	*Explores the carbon emissions reductions that might be possible from the housing stock with detailed modelling of individual energy efficiency measures, the effectiveness of domestic energy efficiency policies and potential future carbon emissions under five separate scenarios, two of which incorporate the Government's target of a 60% reduction in carbon emissions by 2050.*
EA	*Gives an overview of the likely costs and benefits associated with achieving higher resource efficiency standards in the building of new houses under three scenarios: baseline, achievable and aspirational.*
ECI	*Presents a detailed scenario outlining how a 60% reduction in carbon emissions by 2050 could be delivered from the UK residential sector. Discusses the implications for the building fabric, lights and appliances, embedded generation and the energy supply industry.*
Entec	*Examines the environmental impacts of increasing the supply of housing in the UK in line with proposals of the Barker Review. Main emphasis is on land take and economic analysis under four scenarios, with consideration of the associated environmental impacts from construction and occupation. Includes an economic valuation of land in the urban fringe.*
SDC	*Provides an extensive summary of the key issues regarding the existing housing stock, identifying potential actions and policies in each area. More of a qualitative overview – no detailed quantification of savings.*

Whilst there are many areas of overlap across the reports, each study takes a slightly different approach based on differing assumptions, making direct comparison difficult. This is particularly true for energy, where the estimates of potential savings are highly dependent on the underlying assumptions such as emissions factors, the number of households and any increase in energy services. Although none of the various assumptions are necessarily right or wrong, a true comparison between the reports would only be possible if the same set of standard assumptions had been employed. Despite this, there are some areas where a more direct comparison is possible:

- The Bioregional and Entec reports focus on the additional housing required, particularly in the Thames Gateway.
- The implications of building to different standards are considered in the Entec, Bioregional and EA reports.
- The reports by BRE and ECI both incorporate detailed 'bottom-up' modelling of energy consumption in the UK residential sector to 2050.
- Estimates of savings from various technologies and approaches are provided in all the reports, with accompanying cost estimates in some cases.

It should be noted that since the literature review was completed, both the Sustainable Development Commission and Entec (under the ODPM) have produced updated studies in this area: 'Stock take: delivering improvements in existing housing' (SDC 2006a) and 'A sustainability impact study of additional housing scenarios in England' (ODPM 2005a). Although the timing of these reports meant they were largely outside the scope of this study, there are no major issues which fundamentally impact on the literature review. In general the new reports contribute a more comprehensive and detailed analysis and address some of the issues identified in the review here. Specifically, the SDC report incorporates more detailed quantification and further development of policy options. The Entec report addresses land-use in more detail, matching availability and demand, and analyses the water and energy impacts of additional housing considering the implications of the change in occupancy of existing dwellings. This updated report also has a wider scope and considers potential social and economic aspects and regional distributions.

2.1. Socio-technical systems

The reports included in the literature review were considered in the context of socio-technical systems to establish what, if any, assumptions about socio-technical aspects are made in each.

In general, there are no explicit references to theories of socio-technical change in any of the reports. All the studies tend to be fairly technology-focused, concentrating on calculations of the savings achievable through the various technologies, rather than considering the wider socio-technical context in terms of delivering these savings. On some levels, there are good reasons for such a strong techno-focus – the technologies are clearly identifiable, are amenable to policy and the potential savings are (relatively) straightforward to quantify leading to easily-identifiable policy recommendations. This is in contrast to the 'softer' issues such as people and behaviour and the social systems within which they operate, which are much less easy to quantify, model and target through policy. However, one of the problems with avoiding these more complex issues is that the substantial savings predicted in many reports do not appear to be delivered in practice or are hidden by an increase in energy services, although this issue is not specifically discussed in the reports considered.

Of the six reports, the BRE study is the most technology-focused, with the calculations of savings based on a purely economically-rational model in terms of the uptake of cost-effective measures. However, the main thrust of the report is to illustrate the level of savings possible given the available technologies, rather than to discuss how these savings could be achieved. Therefore there is no discussion of the social aspects of the scenarios.

The Entec report is also predominantly technology driven, with the analysis based on the premise that more houses are required and there will be an associated environmental impact as a result. As with the BRE report, the social angle is not addressed explicitly but the analysis provides a framework for a discussion of the issues and the possible implications of the scenarios. The economic analysis of the external impacts does take account of some societal values such as the benefits of landscape quality and recreational opportunities, although only in monetary terms.

Behavioural issues are mentioned in the EA report where a behavioural shift is necessary to achieve the proposed savings, but there is little discussion as to how or why these changes may occur. As with the BRE and Entec studies, the analysis is mainly technology focused with regulation taken to be necessary to achieve the higher standards.

The SDC report contains more of a consideration of the role the various actors, such as householders, government, utilities and the supply chain, have to play in delivering possible savings, and the framework of policies needed to catalyse behavioural change. However, the emphasis is generally around overcoming the ‘barriers’ to deliver the technologies – hence the study is still fairly techno-centric.

The Bioregional and ECI studies address social issues to a greater extent than the other reports, although the analyses still tend to be technology-based. Inherent in Bioregional’s Z^2 scenario is a significant shift towards more sustainable communities where people are more conscious about energy use and consumption in general and happy to live without owning a car – using public transport or walking or cycling instead. In part this is helped through the design of the buildings and space that make up the community, but also requires a change in the people themselves. Although this paints an appealing picture of what a more sustainable society would look like and the resultant savings possible, no detail is provided as to how this shift would occur aside from the assumed influence of new infrastructure shaping behaviour eg car clubs. In other words, it is assumed that a more sustainable physical infrastructure would catalyse a shift towards more sustainable behaviour patterns.

The majority of the ECI report is focused on the technological solutions required to achieve a 60% cut in carbon emissions and the policies which could potentially deliver these reductions, with a consideration of demographic, household and service level changes. In the final chapter, there is some discussion of the implicit assumptions about the type of society which underlies the ‘40% House’ scenario. As with the Bioregional Z^2 scenario this essentially involves a shift towards a more energy and carbon conscious, and less consumptive population across all sectors – including government, builders, developers, manufacturers and the general public. Some of this change is proposed through technology-focused regulation eg of manufacturers to encourage them to produce less energy consuming appliances. But the ECI suggests that the key to such a substantial change in society comes through an overarching framework such as personal carbon trading. This could potentially result in a strong demand from society for low-carbon products and services and thus drive the development of the technology rather than the technologies being ‘imposed’ on society.

In summary, all the reports are heavily biased towards an economically-rational, technology focused model, where it is assumed that the available technologies have the potential to deliver the savings provided the societal and behavioural ‘barriers’ can be overcome. Given that so far these savings across the various impacts have failed to materialise brings into question the validity of this approach in isolation from a wider consideration of the forces and systems within society that are at play. The Bioregional and ECI reports represent a step in the right direction, although the analyses would still benefit from a more in-depth exploration of how society and technology could interact together to bring about the necessary reductions.

2.2. Energy

2.2.1. Overview

Three of the reports considered the existing housing stock in the UK: BRE, ECI and SDC. The BRE and ECI reports are more directly comparable, both providing a detailed quantitative model of household energy consumption to 2050. The SDC report gives a more qualitative picture of the current situation and policy options that could be employed. The emphasis in the BRE report is on quantification and analyses of policies and savings, with little in the way of future policy recommendations. The ECI report lies somewhere between the two, combining detailed modelling with policy proposals and a consideration of the societal shifts required.

There is a strong emphasis on the cost-effectiveness of measures in the BRE report, with cost-effectiveness defined as being cost neutral over a certain payback period. However, these calculations are very dependent on the underlying assumptions such as fuel costs, capital costs, the discount rate and the carbon intensity of electricity, all of which are likely to change in the future. Therefore, current estimates of cost-effectiveness are not a reliable indication of which measures are likely to be cost-effective in the future. Such analyses can provide a useful indication of where effort should be focused and where support through grants etc is most needed if these measures are to be implemented, but there is also a danger that many necessary measures will be ignored because they are not considered ‘cost-effective’. The three sections of the BRE report, although linked to a certain extent, consider the issue from different perspectives and provide different estimates for carbon savings and emissions factors which are not easily comparable.

In contrast, the ECI report does not consider costs at all, stating that cost-effectiveness is likely to change significantly over the 45 years to 2050, although some indicative figures may well have been useful to support the scenario outlined. This report provides the most detailed analysis on energy in the housing stock but does not address any of the wider environmental issues associated with housing. One of the most contentious issues of this report is the proposed increase in demolition rates to deal with the most inefficient properties, but there is a lack of detailed quantification of the embodied energy involved in such an approach compared to refurbishment. The SDC focuses only on refurbishment, considering this preferable to demolition and redevelopment in the context of wider sustainable development. The SDC study does not attempt to model the UK housing stock but uses other studies as the starting point for developing policy recommendations to deliver domestic energy efficiency and carbon reductions.

The Bioregional, EA and Entec reports focus on new build. Both the Bioregional and EA reports explore the savings available from individual new build houses as an illustration of what could be achieved, but do not make any attempt to extend this calculation to the impact on the whole housing stock. Direct comparison between these two reports is useful and some further comparisons can be made with the new build assumptions detailed in the ECI report. The Entec report takes a slightly different angle and is more focused on the potential environmental impact as a result of building additional houses and less focused on the possible savings available, although it does consider the effect of building the houses to different standards.

All three reports (Bioregional, EA and Entec) base their estimates on Ecohomes ratings. Whilst this is a useful benchmark, because the system is based on an overall score built up through points awarded for a variety of parameters, it is not possible to assign specific measures, eg the depth of loft insulation or efficiency of appliances, to a particular rating (‘Very Good’, ‘Excellent’ etc). It is therefore not a particularly useful basis on which to calculate and compare potential savings since the exact steps required to achieve the ratings are not explicit.

Key messages

- The standard of the existing UK housing stock is extremely poor
- If no action is taken then energy consumption and carbon emissions from the housing stock will continue to rise – the current uptake of energy efficiency measures is not sufficient to offset rising demand for housing and energy
- Action must be taken to improve and maximise the energy efficiency potential of the existing stock
- A 60% reduction will only be possible through a combination of major improvements to the building fabric (eg cavity wall insulation and insulation of floors and external walls), substantial increases in the energy efficiency of lights and appliances throughout the stock and the installation of Low and Zero Carbon[3] (LZC) technologies. It is the combination of measures that is important – any one of these interventions on their own will not be sufficient
- Sustainable construction methods need to be adopted by the mainstream for both new-build and refurbishment
- Building Regulations should be extended to cover all refurbishment
- The savings available through current cost-effective measures are limited as uptake increases and reaches saturation – once easy measures have been done it becomes increasingly difficult and expensive to save carbon eg through solid wall insulation (7 million homes) – further research is needed into these areas
- Labelling and minimum standards are effective and necessary and should be expanded to incorporate a wide range of appliances – in combination these can transform the market for new appliances in 5-7 years (although it takes longer to transform the stock)
- Regulation and grants are effective in securing carbon savings for appliances, buildings and LZCs
- Energy efficient options must be available and identifiable if consumers are going to buy them therefore effective product policy is necessary
- There is a significant skills shortage in the construction and planning industry in terms of delivering more sustainable housing and ensuring compliance with Building Regulations
- Greater engagement with the public is needed, with communication of the benefits of more sustainable housing through improved information to householders
- For houses, the point of sale is a key opportunity for intervention, backed up by reduced rates of stamp duty
- Building Regulations are potentially an effective mechanism, but are undermined by poor compliance
- Residential lights and appliances represent a significant area of growth if they remain unchecked, with a substantial increase in electricity demand from consumer electronics in particular. However, this sector also represents an area where significant savings could be achieved through the right mix of policy at both the national and European level
- Air-conditioning is also an area of potentially high growth and steps need to be taken now to avoid such an increase

Areas of significant differences

The BRE and ECI studies are the only two reports that look at the energy demand from the total housing stock over time and incorporate the Energy White Paper target of a 60% reduction in carbon emissions in their analyses. The other reports only quantify savings that can be achieved through new build alone.

[3] The terms Low and Zero Carbon technologies and microgeneration have come to be used interchangeably, and include devices that generate heat or power or both, with lower carbon than conventional sources.

Despite the similarities in approach taken by BRE and ECI, the figures for savings are not directly or easily comparable – differences exist in assumptions regarding the carbon intensity of electricity and the number of households and each study takes a different base year – 1996 by ECI and 2000 by BRE (Table 3). This is complicated by the fact that BRE uses two different figures for emissions factors in different sections of the report and under the different scenarios. However, in terms of the actual level of savings achievable, there appears to be broad agreement between these two studies (Table 4 and Table 5).

Table 3 Comparison of assumptions made by Bioregional, BRE and ECI

		Emissions factors (grid electricity)		Household numbers	
	Baseline year	Baseline (kgC/kWh)	2050 (kgC/kWh)	Baseline (million)	2050 (million)
Bioregional	-	0.242[a]	-	-	-
BRE	2000	0.132/0.126	0.069/0.105 /0.063	24.4	33.3
ECI	1996	0.136	0.100	23.9	31.8

a – ECI calculation based on Bioregional per capita carbon figures and household energy consumption data

As noted above, one of the key differences between the ECI and SDC report appears to be on the issue of demolition versus refurbishment. The SDC favours refurbishment as a first priority in the wider context of sustainable development. The ECI analysis also emphasises the importance of refurbishment to a very high standard but, in addition, includes the demolition and replacement of the least efficient homes, at four times the present rate, in order to achieve a 60% reduction in carbon emissions. The ECI also points out that at current rates of demolition, the average house will have to last around 1300 years. None of the other reports tackle this issue.

Level of potential savings

Table 4 summarises the potential decrease in household energy consumption by end-use from those reports that provided this level of detail. When comparing figures, it should be noted that the BRE and ECI figures relate to the average house in the stock, whereas the Bioregional figures refer to new build only. The main area of significant difference between the stock average and new build figures is space heating – it is unclear why there is such a discrepancy here.

Table 4 Comparison of energy end-use consumption across the reports (kWh pa per household, delivered energy)

	Space heating		**Hot water**		**Cooking**		**Lights and appliances**	
Stock average	Baseline[a]	2050	Baseline	2050	Baseline	2050	Baseline	2050
BRE	13,650	9070	5160	2040	615[c]	480[c]	2910	1470
ECI	14,600	6793	5000	3400[b]	490[c]	129[c]	2514	1550
New build	Baseline	Scen 3	Baseline	Scen 3	Baseline	Scen 3	Baseline	Scen 3
Bioregional	5278	333	3900	3055	614[d]	614[d]	2859	1430

a - Baseline year for BRE is 2000 and for ECI is 1996
b - Excluding solar thermal hot water
c - Electricity only
d - Includes gas and electricity

Table 5 summarises the potential decrease in household energy consumption and associated cost savings proposed in each of the reports. The Entec and Bioregional Scenario 2 figures for new build are similar to those proposed by BRE and ECI in

Scenario 1 for the stock average in 2050 – consistent with transforming the stock so that the average in 2050 (ie existing houses and new build) is equivalent to a high standard (beyond the current Building Regulations) that could be achieved today. In other words, if a 60% reduction in carbon emissions is to be achieved, it is not sufficient just to build new houses to a high standard – existing houses must be brought up to a similar standard through refurbishment and standards for new build need to be even tighter. Carbon emissions under the extreme scenario for Bioregional is far lower – whilst this may represent potential for new build, it will be impossible to achieve this standard within the stock in the next 50 years.

Table 5 Comparison of carbon emissions (energy) per dwelling across the reports

	Baseline[a]		Scenario 1[b]		Scenario 2		Scenario 3	
	tC/yr	£/yr[c]	tC/yr	% cost saving	tC/yr	% cost saving	tC/yr	% cost saving
Stock average								
BRE[d]	1.56	-	0.45 (-72%)	-	-	-	-	-
ECI	1.66		0.46 (-75%)	-	-	-	-	-
New build								
Bioregional	0.84	459	0.56 (-32%)	36	0.56 (-32%)	36	0.001 (-99%)	48
EA	0.47	402	0.35 (-25%)	21	0.1-0.28 (-40-79%)	25	-	-
Entec	1.1	-	0.66 (-40%)	-	0.49 (-55%)	-	-	-

a - Baseline year for BRE is 2000 and for ECI is 1996
b - BRE & ECI scenarios relate to 2050, whereas Bioregional, EA & Entec scenarios represent a static picture of new build, with no associated timescale
c - Costs given for Bioregional & EA relate to the costs of building a house to the standard of current Building Regulations
d - Only reference case and step change 2 scenario shown

In terms of cost savings, Bioregional appears more optimistic than the EA in terms of the financial benefits to the householder. The EA provides no detail as to how these savings were calculated whereas the assumptions behind the Bioregional calculation (eg price of fuel, energy consumption figures) are made explicit, allowing greater confidence in these numbers.

Reasons for lack of uptake

Both the ECI and SDC consider reasons for the lack of uptake of energy efficiency measures within the housing stock. The issues identified include:

- A lack of necessary skills in the construction and refurbishment industry
- Standards set by the Building Regulations are not high enough and compliance is low
- The current planning system and infrastructure
- Split departmental responsibilities
- Weak regulation at the national and European level in terms of product policy
- Low levels of awareness and interest amongst householders
- Low energy prices and high capital costs, accompanied by a lack of incentives
- Confusing fiscal messages

2.2.2. BRE

The BRE report has three distinct sections. The first provides a detailed analysis of the cost-effectiveness of various measures, both for insulation and appliances, at various intervals from now until 2050. As time passes, the study finds that the proportion of cost-effective carbon savings decreases as the most cost-effective measures are taken up and reach saturation point. The carbon savings also decrease due to an assumed drop in the carbon intensity of electricity over time. The report identifies substantial savings through the installation of renewable micro-generation measures by 2050 but calculates that these are not currently cost-effective. BRE assumes two levels of costs for the measures to illustrate a range of possible expenditure and which result in different levels of cost-effective savings (Table 6). As noted in Section 2.2.1, these estimates are highly dependent on the underlying assumptions and measures not considered cost-effective today may become so in the future, particularly if provided with adequate support through, for instance, grants and rebates.

Table 6 BRE estimates of carbon savings from energy-efficiency measures at low and high costs, 2001-2050

	Total savings (MtC/yr)	Total cost £bn		Cost-effective savings (MtC/yr)		Total cost (cost-effective measures) £bn	
		Low	High	Low	High	Low	High
2001	22	123	282	17.5	9	1.9	21
2010	17.5	123	264	13.5	6.5	-	-
2020	13.5	123	249	9.5	3.5	-	-
2050	29.5	313	2034	17.5	0.2	-	-

The second section estimates and compares the savings achieved through a range of policies and programmes, providing an overview of historical progress. Building Regulations and grant-support programmes were found to be equally effective in terms of the carbon saved – both were attributed with saving around 32 MtC each between 1978-2002 (although Building Regulations are cheaper). On average, for each million pounds of grant money, there was an increase in uptake of 3.4 thousand measures, with a total net cost of –£267/tC, indicating a substantial net benefit. The Home Insulation Scheme was found to be most effective when compared with Standards of Performance, the Home Energy Efficiency Scheme and the Energy Conservation Programme. The study also found that the standards set in Building Regulations for new build tend to be adopted as good practice for the refurbishment of existing stock, emphasising the importance of such standards for influencing the whole stock. Savings from appliances and boilers were slightly less due to the shorter period over which measures and policies have been in operation, with 0.32 MtC between 1997-2001 and 1.34 MtC between 1993-2001 respectively. BRE expects that further savings will be realised over the lifetime of these appliances. Total savings for all measures between 1978-2001 are estimated to be 65.32 MtC, with annual savings peaking at 5MtC in 2001 (less than a quarter of the cost-effective potential identified in Table 6). It should be noted that these savings need to be set in the context of increasing demand and population, the net effect being that overall consumption has stayed roughly constant – further and greater savings are required if an actual reduction in consumption is to be achieved.

The third section of the report outlines five scenarios for energy use in the UK housing stock (a reference case, policy scenario, efficiency scenario and two step-change scenarios) and potential carbon savings within this sector. Only the second more dramatic step-change scenario, Scenario 4, achieves a 60% reduction in carbon emissions, primarily through significant installation of LZCs (Table 7).

Table 7 Household carbon emissions per dwelling under the five BRE scenarios[4]

	Household numbers (million)		Baseline 2000	Scenario 1 2050	Scenario 2 2050	Scenario 3 2050	Scenario 4 2050
	2000	2050	tC/yr	tC/yr	tC/yr	tC/yr	tC/yr
BRE (stock average)	24.4	33.3	1.56	1.27	1.05	0.84	0.45

Under Scenario 4, 50% of electricity is generated from zero carbon sources by 2050 and it is assumed that half the heating systems use heat pumps and the other half are based on wood or biomass. BRE estimates that after 2012 the savings outweigh the costs, despite the fact that this was the highest cost scenario of the five modelled.

2.2.3. ECI

The ECI report takes the target of a 60% reduction in carbon emissions as its starting point to investigate the possibility of achieving this level of savings from within the UK housing stock. The study makes a number of assumptions in terms of population growth, household size and the carbon intensity of electricity in the future.

The '40% House' scenario achieves the 60% reduction through a combination of increased efficiency of the building fabric through extensive refurbishment and an extremely high standard for new build, improved efficiency in lights and appliances as well as the installation of a significant level of LZCs (an average of 1.7 per household by 2050). This is equivalent to a 2% reduction per annum between now and 2050, allowing for increases in population. Overall, carbon emissions are reduced by 24 MtC: 15.6 MtC from electricity and 8.3 MtC from gas and the winter peak demand for electricity could be reduced by up to 40%. Implicit within this scenario is the assumption that society has shifted to become more community-minded and environmentally aware.

Under the scenario, energy consumption from lights and appliances is reduced by 50%, with the existing stock refurbished to an average space heating demand of 9000 kWh per annum (taken to be roughly equivalent to current Building Regulations) and new build at 2000 kWh per annum. By 2050, over 80% of heat demand and 100% of electricity demand could be met through LZCs, resulting in the residential sector becoming a net exporter of electricity. The study adopts a dual strategy of refurbishment and replacement, whilst addressing the growth in housing demand (due to increased population and falling household size) through an increased rate of construction, at 220,000 starts per annum for the next 45 years (below the rate assumed for the next fifteen years in the most extreme Entec scenario, although the ECI figure represents the longer-term average). Demolition rates are also increased from current levels of 20,000 to 80,000 per annum by 2016, which could be targeted at the most inefficient dwellings. The report states that the embodied energy in new build is offset by energy savings in use within a few years, provided the new building is built to a sufficiently high standard.

As in the BRE report, renewable energy generation is required to achieve the necessary savings – the ECI study re-iterates the point that costs are currently high since the market for LZCs is relatively new, but these will decrease over time. ECI also emphasises the need for a clear over-arching strategy that deals with both energy and housing needs and that whilst individual targets within such a strategy can be traded off against each other, the options to do so are limited and significant reductions are required across the board.

The study also raises issues such as skills shortages in building, construction and building control checks which need to be addressed, as well as the potential increase in

[4] Note that this calculation is based on GB household numbers but UK carbon emissions figures – the household carbon emissions figures therefore represent a slight overestimate

demand for cooling as the climate warms, which could have significant impacts on energy demand if not carefully regulated.

The report does not include any estimate of the costs associated with the 40% House scenario, based on the fact that what is considered cost-effective is likely to change considerably over the long timescales to 2050 and on the policy route chosen – for instance, minimum standards are much cheaper than grant-support programmes. The study claims that it is necessary to look beyond what is considered to be cost-effective under current energy and equipment prices in order to reach the 60% target.

The ECI outlines a proactive policy approach to achieve the 60% cut, with an emphasis on the importance of addressing equity issues (eg fuel poverty) alongside carbon reductions. The findings indicate that action needs to be taken soon if the target is to be reached.

2.2.4. SDC

The SDC report stresses the need for retrofitting energy-efficiency measures – two-thirds of the existing stock predates any environmental requirement in the Building Regulations (the first national Building Regulations for England and Wales were introduced in 1966).

The SDC report also emphasises the need for densification, with regeneration and infill of existing urban areas to re-use and reinvest in the infrastructure already there, but states that new building on finite land is unsustainable – optimal use of existing developments should be prioritised before approval is given to new developments. SDC states that economics currently favour demolition and rebuild over redevelopment. The report also suggests that use should be made of the 1.5% of English dwellings that are long-term empty homes. Construction has major energy impacts and the embodied energy is six times that for refurbishment (based on figures from the Empty Homes Agency), although the report does not compare this with the lifetime savings in terms of running costs. The report quotes EST figures for the cost of refurbishment up to the standards of the 2002 Building Regulations (for space heating only) as being £500 (1920's semi) to £1100 (1950's terrace), generating cost savings of £150-279 and 80-90% carbon savings. However, there is no demonstration that these can be achieved in practice and no estimation of the impact of increased energy services eg higher temperatures.

The report also stresses the importance of resource efficiency before exploiting alternative resources, thereby avoiding waste, minimising impact and reducing resource use. The SDC suggests that housing policy should focus on minimising energy and wider resource use in existing buildings and proposes a hierarchy of energy efficiency followed by carbon efficient systems and lastly, renewable energy. The SDC study considers the impact of a range of technologies on household carbon emissions, the barriers to their implementation, and proposes a framework of policy interventions to overcome these. Technologies include energy efficiency, energy conservation and microgeneration measures.

The SDC identifies a number of 'barriers' to achieving greater energy efficiency which include lack of information, lack of trust by householders, low energy prices, confusing fiscal messages, high capital costs, the planning system, landlords and the inconvenience factor.

2.2.5. Bioregional

The Bioregional report considers the energy implications of four scenarios with some social/lifestyle elements included. The baseline is taken to be a typical UK home built to 2002 Building Regulations and occupied by a typical UK resident, although no information is given about the type or size of the building. The second scenario is taken to be a typical home built to the Ecohomes 'Very Good' standard, also occupied by a typical UK resident. The final two scenarios assume a societal shift, with an Ecohomes 'Very Good' home occupied by an environmentally-aware resident and finally a Z^2 community – zero fossil energy and zero waste.

Under the baseline scenario, individual emissions are estimated to be 0.36 tC per person per year, equivalent to 0.84 tC per household (a household size of 2.33 is assumed throughout the report). The annual cost of this energy use is given as £197 per person, or £459 per household.

The energy figures for scenarios 2 and 3 remain the same, indicating that the savings are assumed to come through the technology employed rather than through any behavioural shifts. This is questionable, since an 'environmentally-aware' resident would most likely display some energy-conserving behaviour, although there are inherent difficulties in quantifying such changes. Carbon emissions are estimated to be 0.24 tC per person, equivalent to 0.56 tC per household – a 32% reduction. The financial savings are estimated to be £70 per person and therefore £163 per household (relative to the baseline).

In the fourth, Z^2 scenario, fossil energy consumption is reduced dramatically, resulting in annual carbon emissions of 0.0005 tC per person and 0.001 tC per household. Compared to the Bioregional baseline, the Z^2 scenario results in 90% decrease in energy for space heating, 50% for lights and appliances (similar to the ECI 2050 figures) and 20% for hot water. Savings are estimated to be in the region of £94 per person, equivalent to £219 per household – it is unclear whether these figures incorporate any revenue from selling electricity back to the grid. Implicit in this scenario is a community that is willing to live in a more sustainable manner and accept a different way of living eg local food production, more walking and cycling.

The report highlights a theme which is apparent in the other studies: a certain amount of progress can be made through improved insulation and appliance efficiency, but a move to zero carbon requires a shift to LZCs. Given the current high cost of these technologies, the savings to the householder are lower than the energy reductions, but this would change over time if LZCs gain a greater market share resulting in a lower price. The study also acknowledges the embodied energy issue, as raised in the SDC report, but points out that whilst building efficiently may lead to slightly higher embodied energy, this is outweighed by the lifetime savings. In other words, energy efficiency in the building fabric pays off. Building with sustainable energy strategies today is a way of 'future-proofing' developments.

2.2.6. EA

In a similar vein to the Bioregional report, the EA study looks at three scenarios for energy demand, although with no consideration of behavioural issues. The scenarios look at the savings achievable within a typical 3-bed semi-detached house (gross floor area of $100m^2$) if built to higher standards with more efficient technologies. However, these are only quantified for space heating and not for lights and appliances. The 2002 Building Regulations are taken as the base line, which already represent a 50% improvement over the 1990 regulations (assuming full compliance). The report quotes EST figures of 0.47 tC/yr for a typical house built to this standard, compared to the UK average of 1.8 tC/yr. This is nearly half the figure provided by Bioregional, which could be partly explained by different assumptions about the type and size of house on which the calculation is based and because the EA figures only relate to space heating (although this is not stated explicitly in the report).

An achievable standard is defined in line with proposed changes in the Building Regulations and would result in a 25% reduction to 0.35 tC/yr. This is based on a 15% improvement in average U-values through improved insulation, better air-tightness and the installation of energy efficient appliances and dedicated lighting fixtures (although these are not quantified). This is a smaller proportional reduction compared to the Bioregional figures for the 2nd scenario (although the two scenarios are not directly comparable), which are also 0.9 tC above the baseline level given in the EA study. Costs are assumed to be low, in the order of £600, if improvements to the building fabric are incorporated at the design stage. The report suggests that energy efficient appliances could be installed at no extra cost, but this would require appropriate policy support (BRE assumed a cost premium of between £10-£100, depending on the type of appliance). The cost of dedicated light fixtures is taken to be £100. Estimated savings for the household are in the region of £83 per annum, based on figures from the EST best practice standards – substantially different to the figures given by Bioregional, at almost half the amount. Again, it is likely that the EA figures only relate to space heating and so do not include the savings due to more efficient lights and appliances.

An aspirational standard is defined as a 40-100% reduction, to between 0.1-0.28 tC/yr – differing by a factor of at least a hundred compared with the Bioregional's Z^2 scenario. This would require a 40% improvement in U-values and installation of a condensing boiler at a minimum, with adoption of triple glazing and LZCs necessary if further savings are to be achieved. There are no additional requirements for lights and appliances compared with the achievable standard. LED lighting does not feature. Costs to achieve this aspirational standard are potentially high, up to £10,000 per property, depending on the extent to which LZCs are employed – costs here could be reduced through integrating these technologies from the start thereby minimising any additional scaffolding costs. Under this scenario, annual household savings are estimated to be £108, with a potential net benefit of £402 if electricity generated from LZCs is sold back to the grid.

There is only a passing reference to carbon savings and then only to figures quoted in other studies (eg the Entec and Bioregional reports) rather than tying in calculations explicitly with the scenarios provided. The potential to address equity issues through efficiency measures is mentioned but not directly linked to the scenarios outlined.

2.2.7. Entec

The main focus of the Entec report is on the consequences for land-use of building up to an additional 301,000 homes each year (on top of current completion rates), as put forward in the Barker Review (Barker 2004). In terms of energy, the study considers both embodied energy related to the construction of new homes and energy use through occupation of these homes.

The Entec analysis is based on three scenarios which each assume a different household carbon emissions figure. As with the EA and Bioregional studies, the baseline is taken as a typical new build house built to 2002 Building Regulations. In this case, the house is assumed to be a 3-bed, 3 person occupancy of 90 m^2. The second scenario assumes an EcoHomes 'Very Good' rating and the third, an 'Excellent' rating. Entec make no cost estimates for building to these different standards, nor of the savings in running costs.

The baseline scenario assumes emissions of 1.1 tC per household. This is different to both the EA and Bioregional figures, which may partly be due to differences in assumptions about the make-up of the 'typical' house. The Entec calculations are based on the Building Research Establishment Domestic Energy Model, BREDEM-12, which covers total energy usage ie space and water heating, plus lighting, domestic appliances and cooking.

The ‘Very Good’ rated home is assumed to result in emissions of 0.66tC per annum, representing a 40% reduction over the baseline – a larger cut than in either the EA or Bioregional reports. Under the ‘Excellent’ rating, emissions fall to 0.49 tC per annum (just above the baseline figure assumed by the EA), equivalent to a 55% reduction.

The household emissions figures are then applied up to various rates of building, providing an indication of the carbon implications from energy use as a result of building additional houses. Under the most extreme house-building scenario, with a further 301,000 houses built per annum, this would result in an additional 5 MtC/yr by 2016 if built to 2002 Building Regulations, or 2.2 MtC/yr if built to an EcoHomes ‘Excellent’ standard (regardless of any changes in the existing stock). This is equivalent to a 12% or 5% increase respectively on 2001 figures. The report makes the point that building to a higher efficiency means that a higher rate of housing growth can occur for the same carbon impact and that further reductions would be possible through the installation of LZCs, although this is not quantified. There is no detailed discussion or quantification of further mitigation options.

In terms of embodied energy, over the 16 year timescales considered (2000-2016), the embodied energy of construction outweighs energy in occupation in all of the scenarios modelled, although these figures are close to being equal in the baseline scenario. Building to ‘Excellent’ standards reduces energy in use to just below 50% of the embodied energy of construction by 2016 and would require around another 10 years before the energy in use balances out the embodied energy of the building.

The study also undertook an economic analysis of the environmental impacts which found that carbon emissions (from both construction and occupancy) significantly outweigh the other impacts in terms of the cost these emissions pose on society. The costs ranged from £0.5 billion to £3.5 billion, depending on the level of house build. Building to a higher standard and increasing the density of housing both reduce the external costs of energy use. The report recommends that environmental standards for new build should be improved to Very Good or Excellent, with targets for individual impacts and more explicit specification for energy performance and carbon emissions along with the requirement to record data.

3. Modelling energy, land-use and waste

3.1. Background

Alongside the literature review, the other objective of this study was to model the impacts of the UK housing stock in terms of energy use, greenhouse gas emissions, land-use and construction and demolition waste (household waste is not modelled).

The modelling is primarily energy-focused and is based on work undertaken as part of the Building Market Transformation (BMT) project funded by the EPSRC and Carbon Trust as part of the Carbon Vision Buildings programme. BMT took as a starting point the UK Domestic Carbon Model (UKDCM), as used in the 40% House project[5]. There is currently a significant amount of development work ongoing on the model. It is intended that as part of BMT, the model, all the data and assumptions, and analysis work (eg scenarios and sensitivity testing) be made publicly available in late 2006 for users to explore and construct their own scenarios with.

3.2. Model description

A more in-depth description of the modelling process, detailed results and sensitivity analysis is provided in Appendix D.

The UKDCM is a detailed 'bottom-up' model of energy-use in the UK residential sector and incorporates electricity and gas used in space heating, water heating and domestic lights and appliances. The bottom up modelling process combines known historical data and trends with projections about a range of possible futures and what might cause them. Historical data are taken from a range of sources, a major one being the 1996 English Household Condition Survey as well as other House Condition Surveys for Scotland, Wales and Northern Ireland. The baseline therefore takes account of the distributions of energy efficiency in the UK housing at the level of constituent nations. No regional variations are modelled for the stock in the future: the model assumes averages for improvements in performance. This is just as valid as defining a hypothetical distribution for a scenario (and it is considerably quicker and clearer). The numbers in the UKDCM reflect the ownership and use of appliances, the standards of service required and a range of other, external, judgements, made through a combination of expert judgement and existing trends. The land-use and waste calculations are outside the energy model but directly linked through the assumptions used (eg build, demolition and refurbishment rates, housing density and type). The results serve to demonstrate the key interactions between these impacts.

In modelling energy use in households, and specifically in the UKDCM, technology is seen as a key force. But society shapes technology just as technology shapes society. Many aspects of society show up through people's behaviour: what they purchase, what they don't buy; how often they use their possessions; how they respond to electricity and gas prices. Other trends are reflected in the actions of the manufacturers: what types of new products they bring to market and how they are designed to be used; the emphasis placed on different features in advertising campaigns; the commission given to retailers to promote different brands; the speed with which the manufacturers respond to pending legislation. The net effect of all of these is encapsulated in the products that are in people's homes and the buildings themselves – the stock.

[5] See http://www.eci.ox.ac.uk/lowercf/40house.html

There are a number of assumptions and features that underlie all three scenarios modelled and characterise the modelling approach:

- **Demographic change** is in line with central forecasts from the UK Government predicting population growth and a decreasing average household size. In all three scenarios, the UK population is projected to rise from 59.5 million in 2003 to 66.8 million by 2050, with household size decreasing from the current figure of around 2.4 to 2.1, resulting in 31.8 million households in 2050. Even a basic number such as household numbers is uncertain, and sensitivity analysis has been performed around this assumption.
- The impacts of **climate change** on residential energy consumption are dealt with by sensitivity analysis of the model results.
- The focus of the model is on the dwelling and therefore **no centralised 'supply side fixes'** have been modelled. Emissions factors for centralised electricity are assumed to follow Government projections falling from 0.142 kgC/kWh in 2005 to 0.12 kgC/kWh in 2020[6] and then held constant to 2050.
- **Societal influences** are considered in developing estimates for ownership and usage, for example, the impact of falling household size on usage patterns. Under Scenarios B and C, there is an inherent assumption that there has been a general shift towards a more carbon aware society. The way in which this shift has occurred is not explicitly modelled but could result from, for example, a framework such as personal carbon trading or increased taxation.
- **Behavioural factors** are incorporated into the model through estimates of sales, ownership and usage figures, as indicated in Table 8.
- **New technologies** assumed are based on those that are market ready or close to market. Selection of the highest consuming technologies (like set-top boxes and plasma televisions) or lowest consuming technologies (like LED lights, solid state power supplies and vacuum insulated panels for refrigeration) helps define an envelope of potential savings. Consideration has been given as to what this actually means in terms of the necessary societal framework and the types of policies that could help drive these changes.
- **Rural homes** are not treated separately from urban or suburban ones with regard to strategies for improving the fabric of the stock or the consumption from lights and appliances. With LZCs, uptake rates of certain technologies are linked explicitly to density and the availability of mains gas. Ground-source heat pumps are assumed to be primarily suited to rural settings.
- **Policy measures** considered include information (eg labels), regulation (eg minimum product standards or Building Regulations) and fiscal incentives (tax rebates, grants, energy taxes, or personal carbon trading), as in a market transformation approach. Where the impact of a policy is easy to define (usually relating to technical performance eg a minimum standard for refrigerators), it is modelled directly. Where the policy impact is more diffuse or generic (eg personal carbon trading, carbon taxation, development of incentives for Energy Services Companies), the influence of the policy is implicit within the estimates assumed for uptake of more efficient technologies.
- **Economics** is not a determinant of the model, but economic implications of scenarios can be assessed. Economics are not used to determine choices for several reasons. First, people are not (at present) economically rational when it comes to energy investment. They fail to purchase measures which are cost effective (eg cavity wall insulation and loft insulation) yet invest in measures which are not yet cost effective for other reasons, eg double glazing to reduce noise. What governs installation or otherwise has far more to do with social science than economics: availability, understanding, motivation, perceived benefits (eg making a visible statement of values

[6] Based on www.mtprog.com/ApprovedBriefingNotes/BriefingNoteTemplate.aspx?intBriefingNoteID=150#_edn7

that installation of solar water heating makes) rather than payback. Second, to achieve anything like a 60% reduction in carbon emissions would require going beyond those investments described as currently cost effective at today's energy and equipment prices. Finally, over the time frame of the analysis, both energy prices and equipment prices are likely to change substantially. Whilst householders may not act in an economically rational manner, reduced paybacks are still important at the societal level. Large increases in the installation rates of energy efficiency measures and LZCs can dramatically reduce the costs of change through technology learning or experience curves, giving paybacks within five years (Hinnells 2005). Higher energy prices would only reinforce this.

- **Validation**. Modelled energy consumption has been validated against quarterly energy supply from DUKES over 31 quarterly periods: modelled consumption and energy supply data show a high level of agreement.
- **Development of trends.** Future trends often grow out of the extreme ends of the distribution of current technology and behaviour. For example, following minimum efficiency standards, the average refrigerator on the market becomes close to the best currently on the market; there could be a cohort effect for many elements of behaviour, so that future hot water demand and internal temperatures are indicated by what young people demand now; and Building Regulations for the mass market in future could be informed by what self-build projects achieve today. Whilst the model uses an average value for a given year in many cases, this is simply mathematical convenience. What often lies behind that average is an understanding of the distribution and its evolution.

Thus, any detailed model, such as UK Domestic Carbon Model (UKDCM), reflects decisions about a changing society. It has a richness of technical detail but also incorporates socio-technical issues, at least in part. Modelling the future requires expert judgement on the interplay between various social and technical factors: this is not a precise science. Knowledge of past trends and an assessment of a range of future influences (not least the policy environment) are needed. It is not necessary to identify the precise role of each individual influence, merely to reach a judgement on the overall effect. Some examples of the way in which social trends have been reflected in technical data for UKDCM are given in Table 8. There is a hierarchy, inasmuch as certain social developments can be captured successfully in the model whereas others are harder to pin down. In all cases, the inclusion of the effect of a societal trend in a technical model is highly subjective, but this is true of all parameters in a scenario approach. Whether a manufacturer will introduce a new technology, the speed with which it will be developed and whether it will be taken up by society can also only be gauged through expert judgement. And finally, the detail of the links between a trend and the model have to be identified in an accompanying text: for instance, that certain demographic trends are likely to continue, resulting in fewer people per household and more households.

Table 8 Socio-technical interactions within the housing stock

Societal trend	Technology impact	Included in UKDCM
Greater affluence	More and bigger appliances	Yes, through ownership levels and consumption per appliance
Fragmented family lifestyles	More appliances (TVs in children's bedrooms), more cooking (separate meals), more frequent uses of washing machine	Yes, though ownership and usage patterns
Fragmented families (less people per household)	More households, each with their own equipment	Yes through more households
Ageing population	More one and two person households leading to more dwellings, under-occupancy of existing properties and smaller new homes	Yes, through number and size (m^2) of dwellings; higher temperatures in the home from greater hours of occupancy
Fuel poverty	Cold, poorly insulated homes where any energy efficiency improvements are taken largely as greater warmth (rebound effect)	Yes, temperature levels in the home
Heritage protection	Old buildings retained, not demolished; limits to the installation of micro-generation	Yes, through rate of heat loss, ownership of Low and Zero Carbon technologies
Environmental concern to have a lower carbon impact (linked to the introduction of personal carbon trading). Perhaps an indication of feelings of 'sufficiency'	Less appliances purchased; manufacturers only producing new equipment that is energy efficient and necessary	Yes in Scenarios B & C, through lower levels of appliance ownership; less miscellaneous (unexpected) energy growth
Rising fuel prices causes greater fuel poverty	Short-term, more cold homes; long-term more focus in inefficient buildings	No, this would require non-linear trajectories for temperatures in the home and rates of heat loss
Lack of concern for maintenance and energy efficiency of properties	Lower then expected performance due to poor installation of measures and changes over time eg deterioration	No, measures are assumed to be correctly installed with performance meeting design specification

3.2.1. Energy flows in the model

Homes are heated through solar gain, bodies, waste heat from lights and appliances, and heat given off from the hot water tank (although not all this heat is useful because it can occur when no heat is demanded, eg at night or in the summer). The remaining heat need (the useful energy for space heating) is provided as the output from the main heating device. Heat is lost through walls, floor, ceilings, from warm air vented to the outside and through hot water to the drain. In poorly insulated homes, the boiler provides a large portion of the total heat and the rest is regarded as 'incidental gain'. In ultra low-energy homes, 'incidental gains' can provide most, if not all, of the energy required to heat the home. When a home is at a steady temperature, heat losses equal heat inputs.

Much analysis of the UK energy sector is in terms of delivered energy (deliveries by energy companies via pipelines for gas, or the public distribution system for electricity or via merchants for oil and coal). However, this approach is inadequate to really understand demand, especially when incorporating supply from building-integrated Low and Zero Carbon (LZC) technologies. Generation of energy within the home (eg Combined Heat and Power electricity, photovoltaics, micro-wind or solar thermal) would not be counted under conventional definitions of delivered energy, but these provide useful energy. To understand what goes on inside households, the best form of energy analysis is useful energy (energy available after deduction of the losses incurred in the process of conversion to space, process heat, motive power or light). But in order to explore the effect on the wider energy system, useful energy has to be related back to the delivered energy and the primary energy displaced (eg fuels in power stations). Definitions are outlined in full in Appendix D.

3.2.2. Scenarios

Three main scenarios for the UK housing stock were developed for comparison. These scenarios outline what could happen but do not identify the possible causes, eg climate events, energy price shocks, political change. It is also important to bear in mind that these are not forecasts, they are illustrative projections of the nature of, 'if this happens, then the implication is this'. No likelihood is attached to any of the projections. The scenarios are focused on energy consumption, but with implications for land-use and construction and demolition waste.

The underlying philosophy for each scenario was established to help determine the numbers, assumptions and policy measures adopted in each:

1. **Scenario A**
   The aim is to represent a plausible scenario to illustrate what would happen if change was incremental. Scenario A reflects the continuation of current and near-term trends, technologies, policies and practices, with changes occurring slowly into the future. Society is assumed to continue along current trends with no restriction on consumption and any uptake of new energy-efficiency technology is slow (eg the rate of uptake of Combined Heat and Power is based on historic uptake rates for condensing boilers). Consumer electronics is seen as a major growth area with rapid uptake of new technologies such as plasma televisions and Third Generation (3G) phones with portable television capability (which could displace second TVs in the home). The next 50 years would be similar in character to the last 30 years: whilst there have been (and will continue to be) significant energy efficiency and renewables programmes (eg Low Carbon Buildings Programme), improvements in efficiency would largely be outweighed by increasing demand for energy using products and services driven by an increasingly wealthy society eg cooling products and outdoor goods such as conservatories, patio heaters, hot tubs and swimming pools.

2. **Scenario B**
   This scenario investigates how the residential sector could achieve the Government's target of a 60% reduction in carbon emissions in 2050, equivalent to the scenario detailed in the 40% House report (Boardman *et al.* 2005). There is an implicit assumption that society becomes more carbon and energy aware, with technological change and societal choice driven by a need to reduce carbon emissions. There is substantial refurbishment and demolition of existing homes, new homes being built with near-zero space heating demand and with higher penetration of renewables and LZC technologies such as fuel cells. Where available, products use gas rather than electricity because of its lower carbon content (eg gas ovens and gas tumble dryers). Products which are energy-profligate and non-essential (such as gas burning patio heaters or electric cooling) are purchased less or technologies are deployed which have no net carbon implication (log burners or solar driven cooling).

3. **Scenario C**
   Scenario C explores the options for a greater reduction in carbon emissions below 60% through further demolition and new build, higher uptake of renewables and energy efficiency measures, and more fuel switching. Aiming for Scenario C may be necessary to ensure that a 60% reduction is achieved in practice, because some investments do not deliver the expected savings, or because of unexpected social trends (eg higher immigration). It may also be necessary to go beyond the 60% reduction to allow for failure to deliver in other sectors or if it is decided that the 60% target does not go far enough to stabilise atmospheric conditions.

A summary of some of the key assumptions underlying each of the scenarios is provided in Table 9. The detailed assumptions are discussed further in Appendix D.

Table 9 Key assumptions of Scenarios A, B & C

	Scenario A	**Scenario B**	**Scenario C**
Headline approach	• Current policy and incremental technical change	• Aim for 60% carbon reduction by 2050	• Aim for 75% carbon reduction by 2050
Demolition rate	• Remains at current levels	• Increased four-fold over current levels	• Increased to over five times current levels
Internal temperatures (demanded of heating system for 46% of year)	• Saturates at 23°C	• Saturates at 22°C	• Saturates at 21°C
External temperatures	• Modelling has been based on historic temperatures between 1970 and 2000. The effects of climate change (eg on summer /winter and day /night temperatures) are uncertain, and changes have been modelled as part of the sensitivity analysis.		
Space heating demand	• Improvements in efficiency have historically been outweighed by increases in internal temperature. Once internal temperature saturates, improvements in space heating are then taken as reductions in consumption	• Decreases more quickly due to a faster rate of improvements and lower internal temperatures	• Decreases more rapidly and goes further (eg through more external wall insulation)
Hot water demand	• Increases in line with current trends to 28% higher per person than current levels by 2050	• Water use increases in line with current trends to 2020 and saturates at 14% higher per person than current levels	• Water use increases in line with current trends, saturating at 8% higher per person than current
Lights and appliances consumption	• Increases due to higher income (more appliance ownership) • New energy-intensive products emerge, including cooling and more outdoor products (eg more hot-tubs, patio heaters)	• Decreases through improvements in efficiency via significant policy intervention as well as fuel switching	• Decreases further through greater improvements in efficiency via significant policy intervention and fuel switching
Low and Zero Carbon technologies (LZC)	• Gas boilers (heat-only) are still the dominant technology for space & water heating with low uptake of LZC (**38**% ownership in 2050)	• Uptake of LZC is higher, reaching **89**% ownership in 2050	• Uptake of LZC reaches **115**% ownership in 2050, but with a higher proportion of renewables relative to Scenario B

3.2.3. Housing stock assumptions

The key link between the UKDCM energy model and the land-use calculations is the demolition rate used as an input to the model which, given the assumed growth in number of households, determines the level of new build required – both to replace demolished dwellings and meet additional demand (Appendix H & I). Table 10 summarises the changes to the housing stock under each of the scenarios as a consequence of the assumed demolition rates.

Table 10 Housing stock scenarios

	Scenario A	Scenario B	Scenario C
Demolition rate (annual)	17,000	71,000	89,000
New-build rate (annual)	169,000	222,000	240,000
Total new homes, 2005-2050	7.6m	10.0m	10.8m
Total demolished, 2005-2050	0.8m	3.2m	4.0m
Stock turnover in 2050 (years)	1900	400	300

The demolition and new-build figures are shown as annual averages, but in reality it is likely that in all three scenarios the rate of new build would be higher initially to address the current shortfall of housing, creating a surplus to reduce prices. The demolition rate would be ramped up in the following years and then continue in parallel with new-build.

3.2.4. Land-use assumptions

Key assumptions specific to the land-use calculations (Appendix F) include:

- A mean demolition density of 40 dwellings per hectare under all three scenarios. Given the lack of data on density or dwelling types currently being demolished, demolition is not targeted at specific housing types in any of the scenarios
- All new build (replacement and additional dwellings) occurs on all available previously developed land (PDL) in the first instance. This assumes that all the land can be used and that none is required for non-residential purposes. Once this is used up, building occurs on greenfield sites. No distinction is made between greenbelt and greenfield land.
- The pool of available PDL is assumed to be that which exists in 2004 and that freed up by residential demolition in the ensuing years. No account has been taken of additional PDL arising from non-residential sites after 2004.
- The land-use calculation only takes account of the land required for the house and garden and does not include any additional land for infrastructure eg roads, schools, parks etc. In this analysis, 'dwelling density' refers to the land occupied by the house and garden only.

3.2.5. Waste assumptions

The three scenarios reflect a range of possible futures for the construction and demolition waste industry. Improvements are made through waste minimisation (not generating so much waste in the first place) and through a hierarchy of final disposal options (worst first): landfill, recycling, re-use. Scenario C (and B to a lesser extent) would require significant changes to current practices and possibly new means of brokering and storing 'waste' so that it becomes a valued local resource. The assumptions behind the three scenarios are summarised below, with more detail provided in Appendix G.

Scenario A

Most waste goes to landfill (about 70%), with the remainder recycled and only 2-3% re-used. Construction waste per dwelling is relatively high (reflecting wasteful practices) but refurbishment waste is relatively low because the extent of refurbishment work is limited. Most excavation waste goes to landfill.

Scenario B

More than half of all waste is recycled, with a lower proportion being sent to landfill and a higher proportion re-used than in scenario A. The quantity of construction waste produced is three-quarters of that in scenario A (reflecting better waste minimisation practices), while refurbishment waste per dwelling increases six-fold (due to a more ambitious programme of refurbishment for energy conservation). Half of excavation waste is re-used, eg for landscaping on-site or in nearby projects.

Scenario C
The emphasis is on re-use rather than recycling involving careful, often time-consuming practices. About half of demolition waste is re-used, with a quarter recycled and a quarter sent to landfill. Construction waste is half the level of scenario A, taking the waste minimisation regime even further than in scenario B. Refurbishment waste is 8 times higher than scenario A with 10% being re-used and the majority of the remainder being recycled. Only 20% of excavation waste goes to landfill, the majority being re-used on-site or locally.

3.3. Model outputs: carbon and energy

The headline figures from the model are presented in terms of carbon emissions, with the results from the three scenarios shown in Figure 1 and a decadal breakdown provided in Table 11. All scenarios show a decrease in carbon emissions by 2050, although the reduction under Scenario A is minimal. In summary:

- In **Scenario A**, carbon emissions continue to rise and do not fall below 1996 levels for another three decades. Emissions in 2050 are only 8% below 1996 levels, even with what is considered by Government to be significant policy already in place to constrain emissions.
- In **Scenario B**, emissions fall to 44% of 1996 levels.
- In **Scenario C**, emissions fall to 25% of 1996 levels.

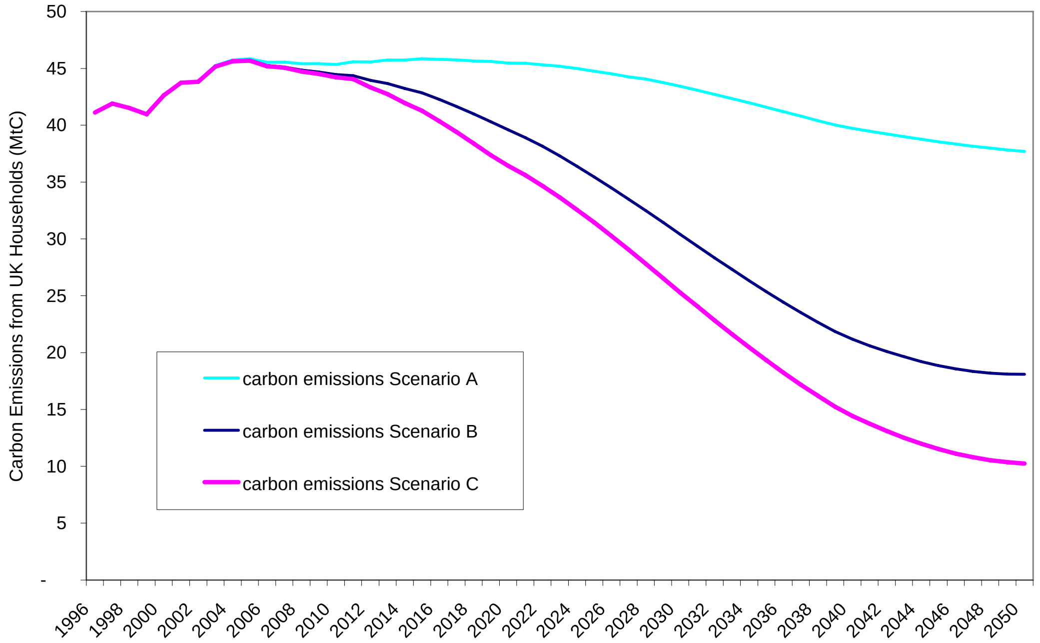

Figure 1 Carbon emissions from UK households, Scenarios A, B and C

Table 11 Carbon emissions from UK households, Scenarios A, B & C

	Scenario A (MtC)	Scenario B (MtC)	Scenario C (MtC)
1996	41.1	41.1	41.1
2000	42.6	42.6	42.6
2005	45.8	45.7	45.7
2010	45.4	44.5	44.2
2020	45.5	39.6	36.4
2030	43.4	30.4	25.3
2040	39.7	21.2	14.4
2050	37.7	18.1	10.2

These carbon savings are achieved through reductions in space heating demand, more efficient lights and appliances, and the installation of Low and Zero Carbon sources of energy within the home. The relative contribution of these factors to the savings varies between the scenarios, depending on the underlying assumptions made in each case. These differences are explored in the following sections.

3.3.1. Relative impacts of refurbished stock and new-build homes

Figure 2, Figure 3 and Figure 4 show the carbon emissions reductions for the entire housing stock under the three scenarios. The area under each graph represents the total carbon emissions from the housing stock: a product of the number of homes (on the x-axis) and the average annual carbon emissions per home (y axis). The total for 2005 is shown in the largest rectangle on each diagram and the total for 2050 under each scenario is the sum of the three remaining rectangles – refurbished stock in 2050, new dwellings for old by 2050 and additional new houses in 2050. It should be emphasised that the term 'refurbished' here covers much more than just the building fabric and represents a 'whole systems' approach – it includes both demand reduction and the installation of LZCs. The total in 2050, at different levels for each scenario, is a combination of:

- refurbishment to existing stock
- demand reduction for lights and appliances (in all homes)
- replacement of some old housing with new housing (ie demolition and new-build)
- new homes to meet projected demand
- installation of LZC across the entire stock

These figures serve to illustrate the relative importance of refurbishment compared with new build in terms of carbon reductions, highlighting the fact that the major challenge lies in dealing with the existing stock. The standard of the additional dwellings built to meet projected housing demand is also important – as Figure 2 demonstrates, new build can result in significant carbon emissions if not built to a high enough standard.

Scenario A represents a modest reduction in carbon as a result of slight improvements to the building fabric and lights and appliances, in line with current trends, along with a low level of LZC installation. The major reductions illustrated in Figure 3 and Figure 4 are due to both significant demand reduction and major installation of LZCs, with Scenario C incorporating even tighter standards and more renewables-based LZC than Scenario B.

The increased rate of demolition in both B and C provides an opportunity to build more new houses to a higher standard. Energy demand for space heating is actually much lower in new build compared with the refurbished dwellings, but this difference is minimised in carbon terms (the relative heights of the 'refurbished stock' and 'new' rectangles) only because the heat-driven LZC in the refurbished stock (eg combined heat and power, biomass and heat pumps) are at a higher capacity and are working harder than those installed in new-build. The carbon benefit of LZC in the refurbished stock is thus greater than that in new-build because the LZCs are meeting a higher demand in refurbished dwellings. However, it is important to focus on demand reduction first (the lower cost option) and then meet this demand through the appropriate level of LZC. Without the LZC (or similar low-carbon source of electricity and heat), the carbon emissions from both the refurbished stock and new build would be much higher.

A lower rate of demolition in Scenarios B and C would mean that (in order to achieve the same carbon reductions) refurbishment of the existing stock would have to go beyond the already challenging levels proposed under these scenarios – both in terms of demand reduction and LZC installation. The technology is available, so, from an energy perspective, it essentially comes down to a decision about which approach is politically and socially more acceptable and more cost-effective in terms of carbon savings.

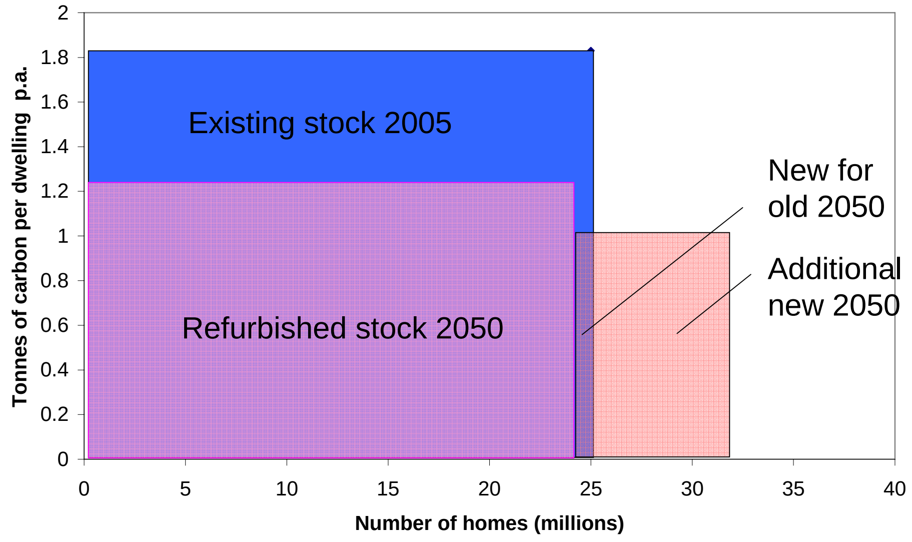

Figure 2 Carbon emissions from refurbished and new-build homes, scenario A

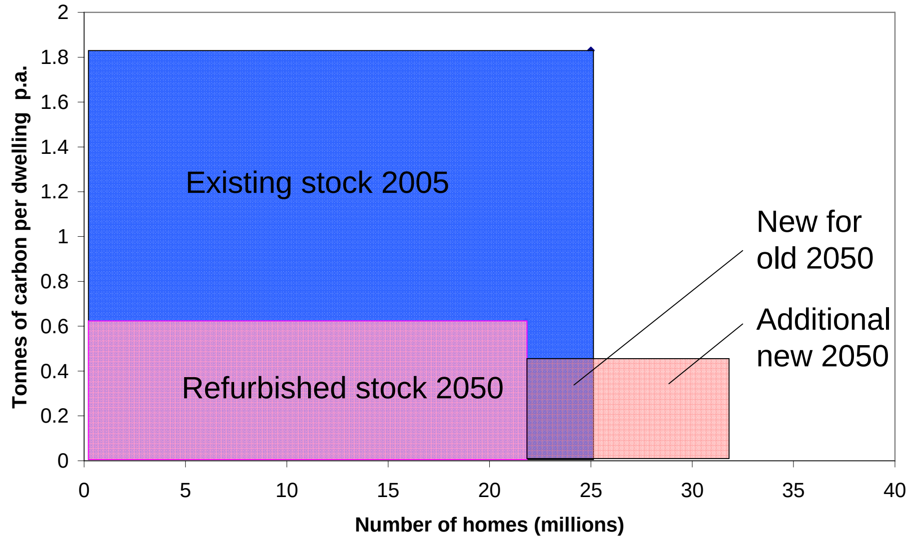

Figure 3 Carbon emissions from refurbished and new-build homes, scenario B

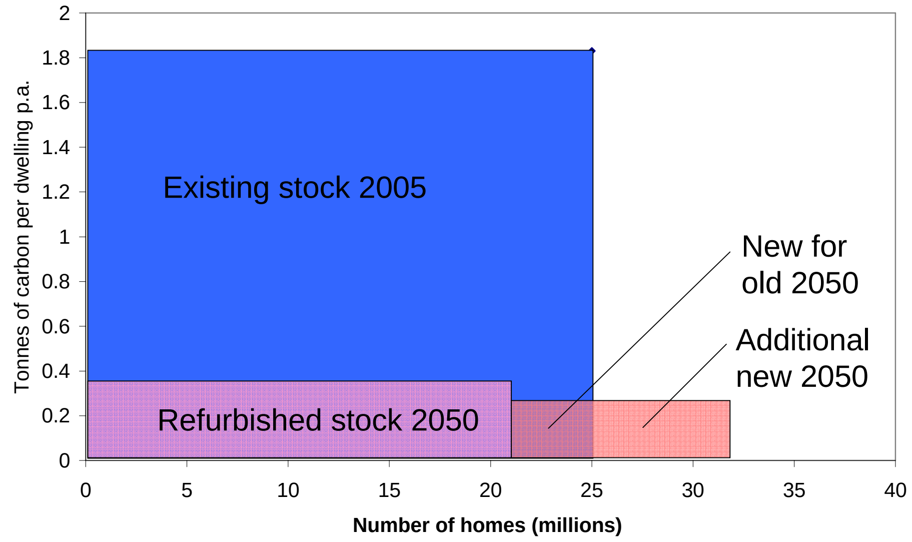

Figure 4 Carbon emissions from refurbished and new-build homes, scenario C

3.3.2. Reductions in space heating demand

Heat demand has been and is still rising, as higher internal temperatures are demanded (Figure 5). Improvements in efficiency have been more than outweighed historically by increases in internal temperatures. As internal temperatures saturate, improvements in efficiency are more likely to be taken as reductions in consumption. Hot water demand also continues to rise but losses from the storage tank continue to fall. There remains potential to reduce this loss, which is achieved in Scenario C. An additional effect in both existing and new build is that as lights and appliances improve in efficiency, the heat gain from them falls.

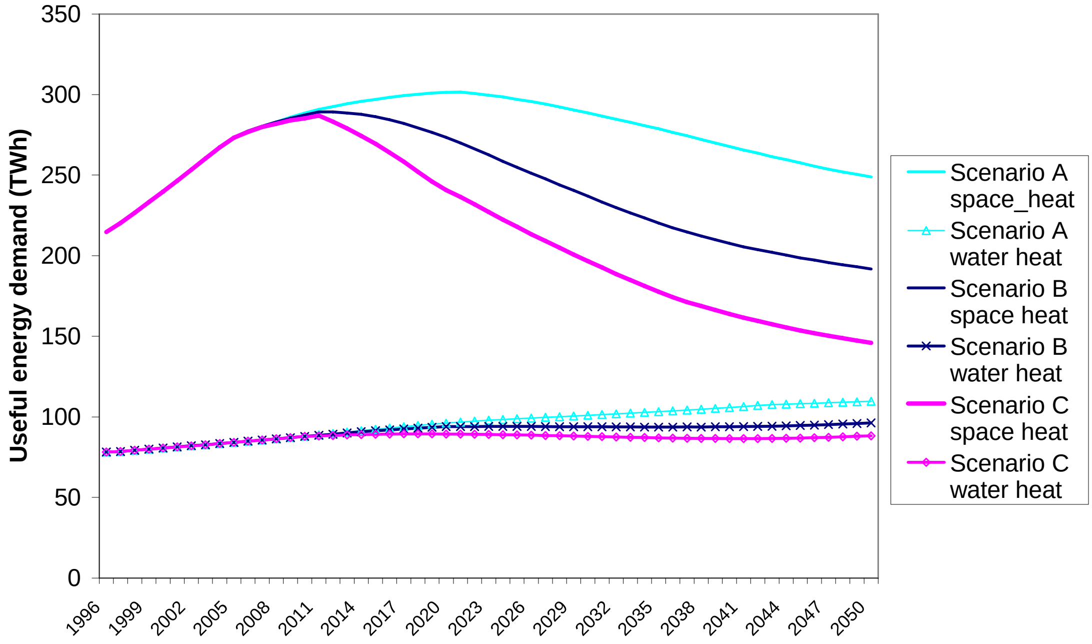

Figure 5 Space and water heating demand, Scenarios A, B & C

3.3.3. Lights and appliances

The development of lights and appliances is analysed by appliance group in Appendix D. In headline terms, in Scenario A the growth in appliance consumption seen in recent decades is expected to continue, fuelled both by new households and wealthier households buying new products and no constraints on manufacturers. A particular issue is the expansion of a group of outdoor products where ownership is already increasing rapidly, albeit from a low base (hot tubs, swimming pools, patio heaters and conservatories). Scenarios B and C include a combination of more efficient appliances, fuel switching from electric to gas appliances, as well as fewer new high consuming products (Figure 6).

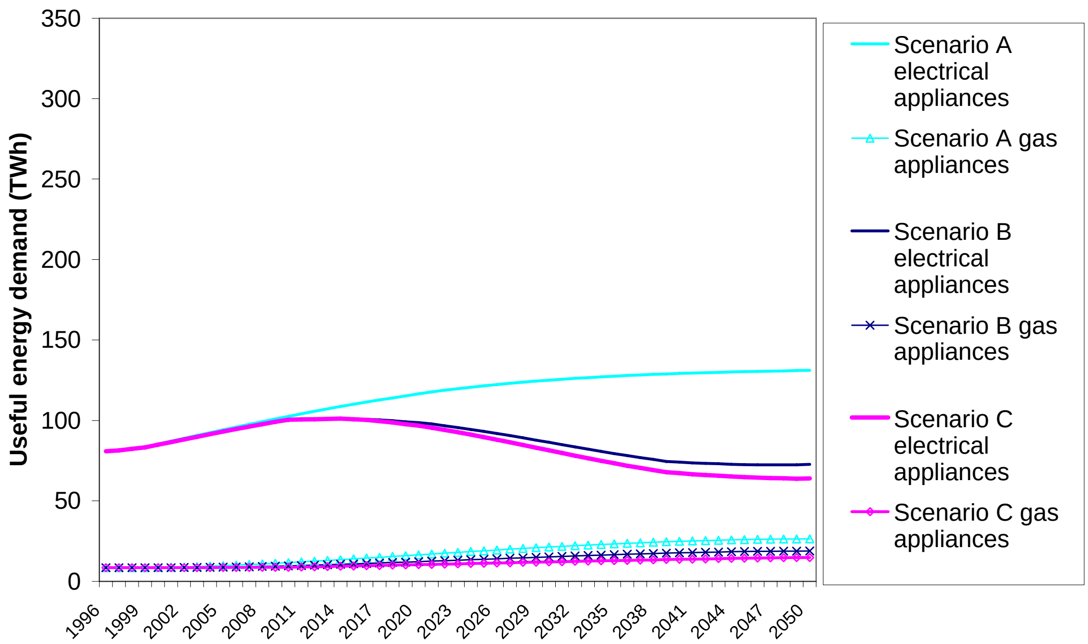

Figure 6 Electricity and gas use in lights and appliances, Scenarios A, B & C

Electricity in lights and appliances is important in terms of the difference in carbon emissions between scenarios because of the higher carbon content of electricity: in Scenario A, consumption in lighting and appliances is rising faster and could carry on doing so and there is also less grid supplied electricity (because of LZCs) in Scenarios B and C.

3.3.4. Low and Zero Carbon technologies

By 2050, in Scenarios B and C, conventional use of grid supplied electricity and gas in heat-only boilers has largely been replaced by a range of LZC technologies. The appropriate technology depends on the type and density of housing, and availability of fuel. In urban areas with dense housing, the most appropriate solution is district heating with biomass or energy from waste (in the form of anaerobic digestion or pyrolysis) alongside gas. In suburban areas, micro-CHP is the most appropriate technology (with Stirling engines in the near term and fuel cells later). Where there is no gas, and insufficient building density for a heat network, biomass heat-only boilers and heat pumps may be appropriate. Rooftop devices (solar thermal, solar PV and building integrated wind) cumulatively make a significant contribution in all areas. Such strategies for LZC deployment are supported by several studies from a range of organisations and perspectives (eg EST 2003, Hitchen 2004, RCEP 2004, DTI 2005, ICE & RPA 2005).

Scenarios B and C show significant reductions of gas and electricity supplied to homes, compared to Scenario A (Figure 7). This would have significant benefits in terms of security of supply, which is important for current discussions about future sources of gas supply as well as future electricity generation capacity; in 2020 under Scenarios B and C, 143 and 170 TWh respectively of electricity from the grid could be avoided, equivalent to 4.4 and 5.7GW of new central electricity generating plant, rising to 25GW and 30GW by 2050. In terms of gas use in the home, scenario B saves 28 TWh in 2020 and 69 TWh in 2050, and scenario C saves 30 TWh in 2020 and 120 TWh in 2050.

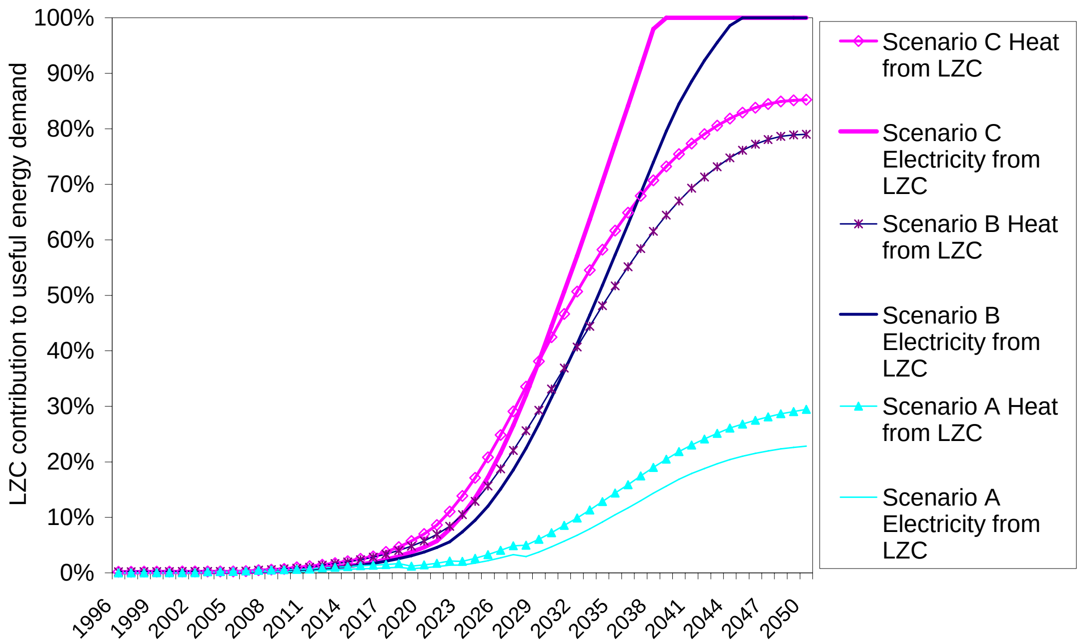

Figure 7 Heat and electricity supplied by LZC, Scenarios A, B & C

Ownership of LZC varies by a factor of three between Scenario A and C (Table 12), with LZC providing the majority of heat and all electricity for homes under Scenarios B and C. For both these scenarios, electricity generation rises to 100% of use in homes on a year round basis. At this level, LZC electricity generation could saturate. Or homes could be providing electricity, eg for use in the production of hydrogen for fuel cells in cars.

Table 12 Heat and electricity from LZC in 2050, Scenarios A, B & C[7]

2050	Ownership (%)	Heat supplied (TWh)	Heat supplied (%)	Electricity supplied (TWh)	Electricity supplied (%)
Scenario A	38%	121	29%	41	23%
Scenario B	89%	332	79%	116	100%
Scenario C	115%	314	85%	126	100%

In Scenario A, the level of LZC foreseen could be provided entirely in new build housing. Scenarios B and C require significant LZC in both refurbishment and new build. LZC could be required, for instance, by planning (in new build), through public procurement (eg public investment in social housing) or Building Regulations (in both new build and refurbishments).

3.3.5. Sensitivity analysis

Factors mutable to policy (such as ownership of air conditioning) are dealt with as part of the scenario analysis. However, the outputs of the model are highly dependent on inputs assumed. In order to explore the impact of changes in certain key input variables a sensitivity analysis was carried out. This was mainly on factors beyond the scope of policy to affect such as population projections and internal/external temperatures. By considering a possible range for the input variables, eg a 10% increase in population, the impact on the model outputs was estimated, expressed here in terms of the percentage change in the carbon emissions for 2050 given in Table 11.

[7] Scenarios B and C represent a similar outcome (energy supplied) from the 40% House scenario, but a lower level of ownership because the output of devices assumed in 40% House was lower

- **Population** projections are notoriously uncertain. Successive population forecasts have had higher and higher peaks occurring later and later. Population could be higher than Government projections for very plausible reasons, such as a high level of immigration, or a significant increase in life expectancy from new and expected medical advances. Assuming that a larger population is served by building more new (and therefore efficient) homes, a 10% increase in population would imply a 3% increase in carbon emissions from each scenario in 2050 (eg under Scenario A, 2050 emissions would rise from 37.7 MtC to 38.8 MtC).
- Other factors could mean a higher number of new homes, even with the same population, eg household size may fall further than expected and second home ownership could increase dramatically with income. This would have a similar energy impact as a higher population.
- The aim of the model is to explore solutions within the housing stock, rather than depend on solutions outside it. However, the **carbon content of grid supplied electricity** could vary with time, and this could affect carbon savings under each scenario. Indeed, it is possible to conceive of solutions being outside the household sector, ‘hidden’ from consumers, and at large scale, rather than being integrated into homes. The impact on Scenario A of electricity being completely carbon-free (ie some combination of nuclear, renewables and carbon capture and storage for fossil fuels) would be a halving of emissions in 2050 from 38 to 21MtC. Thus the 60% reduction target (to 16 MtC) would almost be met but falls short due to the remaining carbon content of heat (as opposed to electricity). The effect on Scenarios B and C is minimal, since in 2050, homes are zero net importers of electrical power from the grid and so emissions under these scenarios are unaffected by any changes in the grid supply.
- **Internal and external temperature** assumptions are an important driver in energy consumption and in the modelling. The model is based on mean external temperatures for the UK 1971-2000. However, there are uncertainties: there is a lack of measured data to confirm current internal temperatures, let alone long terms trends, and there is the possibility of future global temperature rise due to climate change. An increase or decrease in the temperature difference between internal and external temperatures of 2ºC, during periods of heating, would result in a change of +/- 8 to 10% across the scenarios (eg under Scenario A, a 2ºC increase in external temperatures would result in a drop in emissions to 35 MtC in 2050). There is a natural limit to what reductions in temperature could achieve: assuming no space heating at all in Scenario A (ie internal temperatures are a few degrees above ambient, allowing for incidental gains) only delivers a 45% reduction in carbon emissions.
- One of the measures proposed for new-build is improved **air-tightness**, but this may drive an increase in natural ventilation through people opening windows during the heating season. This would be expected to add 8-10% to carbon emissions in 2050. Thus human behaviour may confound the intent of policymakers. One possible solution to minimise this effect would be through mechanical ventilation and heat recovery, provided people use the technology in the way that is intended.

3.4. Modelling outputs: Land-use

The aim of the land-use calculation is to provide an indication of the amount of land required for the additional houses built between now and 2050 to meet projected demand. These calculations are intended to be mainly illustrative – detailed analysis of regional variations and the full range of densities for new build and demolition was not undertaken for this study. A more in-depth examination of dwelling densities and land-take is provided in the recent ODPM report, ‘A sustainability impact study of additional housing scenarios in England’ (ODPM 2005a).

In the UKDCM, each scenario is based on the same total number of dwellings (31.8 million) in 2050. The difference between the scenarios in terms of land-use is due to changes in the demolition, and therefore new build, rate (Table 10), which alter overall housing density and therefore impact on the land required. The following analysis is highly dependent on the density of demolished dwellings.

It is possible to reduce greenfield take by building more dense housing developments and/or targeting less dense housing for demolition. Since demolition is not normally targeted at a building's density, the focus was on the impact of changing new build densities on greenfield take (Table 13). It is assumed that all previously-developed land (PDL) is used for residential housing, although at present only 11% of current PDL is considered suitable for development (NLUD 2004), which would significantly increase the amount of greenfield land required.

Table 13 Estimates of land-use under Scenarios A, B & C in 2050 for various new build densities

Mean new building density (dwellings/ha)	Greenfield take (000s ha pa)		
	Scenario A	**Scenario B**	**Scenario C**
25	220	256	268
40	106	106	106

Given that the mean demolition density is assumed to be 40 dwellings per hectare, building replacement dwellings at a lower density (25 dwellings per hectare) results in higher greenfield take under Scenarios B and C due to the higher demolition rates under these scenarios compared to Scenario A. Where demolition and new build densities are the same (40 dwellings per hectare), greenfield take is equal across the scenarios since net new build (extra over demolition replacement) is identical at 6.8 million additional dwellings between 2005 and 2050.

In order to minimise greenfield take to zero (Table 14), new build density needs to be highest under Scenario A due to the low rates of demolition. Under Scenarios B and C, more land is released through higher demolition, thereby allowing increased densification of a greater proportion of the housing stock.

Table 14 Estimates of build densities under Scenarios A, B & C in 2050 to minimise greenfield take

Greenfield take (000s ha pa)	Mean new building density (dwellings/ha)		
	Scenario A	**Scenario B**	**Scenario C**
0	90	69	66

Government planning guidance PPG3 (ODPM 2005b) currently encourages densities of between 30 and 50 dwellings per hectare for new build. However, the levels of new build density in Table 14 are not unrealistic – net dwelling densities for new developments have been increasing and reached 73 dwellings per hectare for London in 2004 and an average of 47 dwellings per hectare across England, with recent housing developments ranging from 17 to 400 dwellings per hectare (ODPM 2005a). This compares with a mean of 300 for central Paris and 500 for central Barcelona.

These calculations serve to illustrate the key interactions between overall land-use with the density and rate of demolition, and the density of new build. With an appropriate demolition strategy and by utilising higher densities, it would be possible to preserve current greenfield sites.

3.5. Modelling outputs: Embodied energy and construction and demolition waste

3.5.1. Embodied energy

The process of building new homes or carrying out refurbishment work requires energy inputs at various stages – extraction of raw materials; materials processing; turning processed materials into products; final assembly. There are also transport energy impacts throughout the supply chain. All of this embodied energy needs to be taken into account when assessing the overall impact of building work: it only makes sense in energy terms if there is a significant net reduction as a result of doing the work. So, when considering a strategy for housing renewal, it is important to take into account the relative energy impacts of demolition, new build and refurbishment which result from the interaction of several key variables:

- embodied energy of new-build;
- operational energy (for space heating) of new-build;
- embodied energy of refurbishment;
- operational energy (for space heating) of refurbishment; and
- time period of the comparison.

Embodied energy figures of 90 MWh (new-build) and 15 MWh (major refurbishment) have been assumed in this analysis as mid-range figures based on a number of estimates (Appendix E). There is widespread agreement that the impact of operational energy far outweighs embodied energy for the UK's inefficient housing stock over any sensible timescale. The prime objective should therefore be to reduce operational energy (Sustainable Homes 1999, XCO2 2002). The combination of embodied and operational energy use in UK homes over 60 years is far more sensitive to the heat loss (ie amount of insulation) than it is to the energy used to produce, transport and install the insulation material (Figure 8). The energy benefit of renewing housing becomes much more pronounced if the turnover of the housing stock were to remain at over 1300 years as at present.

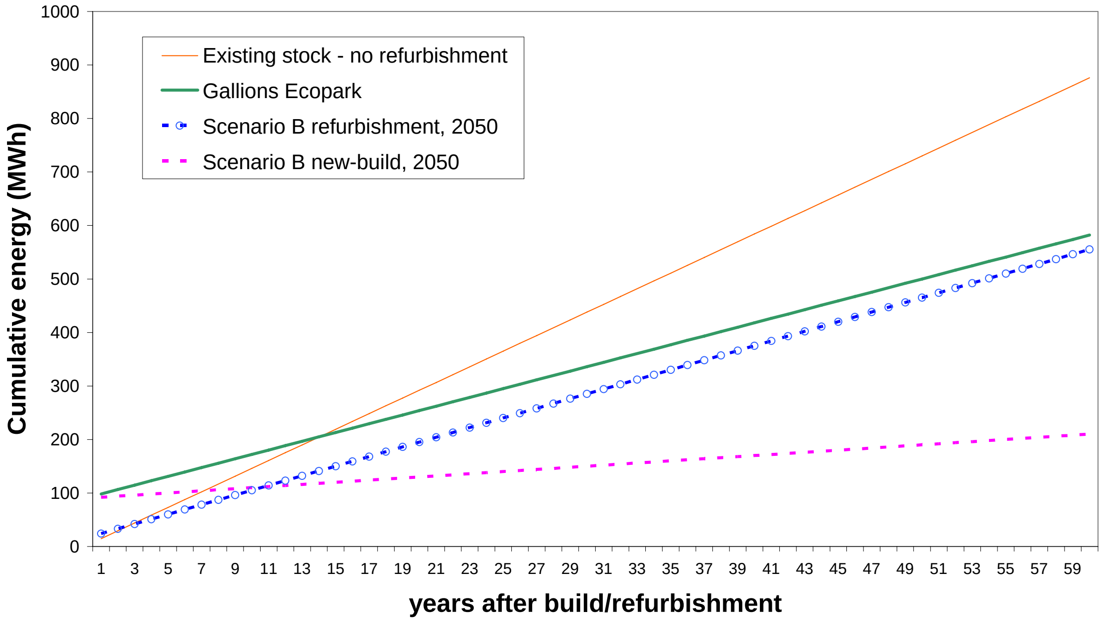

Figure 8 Comparison of embodied and operational energy for refurbishment and new-build

Figure 8 can be read as two pairs of lines: the top two (on the right-hand side) represent the 1996 stock average of 14.6 MWh delivered energy per year for space heating (with zero embodied energy) and an example of a recent development, Gallions Ecopark in Greenwich, with an average of 8.2 MWh delivered energy per year for space heating (Joosten et al 2004) and 90 MWh embodied energy. The Gallions Ecopark development was built to Ecohomes 'excellent' standards – the most stringent standards used by the mainstream construction industry – and is used here as an example of current 'good practice'. The lower pair of lines on the graph represent Scenario B levels of refurbishment (15 MWh embodied energy) and Scenario B new-build standard (90 MWh embodied energy). There are several key messages from Figure 8:

- Taking into account both embodied energy and operational energy, the impact of the new-build home is lower than the existing house after 11-13 years; after 60 years the total energy of the new-build home (ie embodied and operational) is significantly less than the total energy consumed in running the existing home. Thus embodied energy is no reason not to demolish, although there may be other reasons (eg social, heritage) why demolition is not appropriate.
- Demolition and re-build is only beneficial over refurbishment in energy terms provided that the new homes are built to a high enough standard. If the homes are only re-built to the standard of the 'Gallions Ecopark', then there would be little difference in overall energy consumption.
- If new dwellings are only built to the standard of Gallions Ecopark, the 60% target will not be achieved – standards for new-build have to be made much more ambitious, eg a maximum of 15 kWh/m^2/year for space heating (Passivhaus 2006) ie close to zero space heating demand.
- In combination with low-energy new-build, existing housing must be refurbished to a maximum average space heating demand of 8.2 MWh in order to reach the 60% target
- The benefit of renewing housing to a high standard is substantial and would remain so even if the embodied energy figures were doubled. It therefore makes sense to invest in extra material (eg for insulation, thermal mass) at the construction stage and pay an embodied energy 'penalty' if the result is a genuinely low-energy home.

3.5.2. Construction waste

An inevitable consequence of increasing the rate of housing renewal is a greater pressure on the levels of construction and demolition waste produced. The modelling of this sector sets out to analyse the implications of the different build and demolition rates under the three scenarios. As with the land-use calculation, these calculations are intended to be illustrative, to highlight the key issues and interactions within the housing sector.

Detailed assumptions about the modelling are given in Appendix G. There is low certainty about several key input variables because of the lack of reliable input data. For example, estimates for the mass of a single dwelling vary between about 120 tonnes (Jones, pers. comm.) for new homes to nearer 200 tonnes for BedZED (which incorporates more insulation material and heavy structural elements as part of its low-energy strategy). No data could be found for the mass of typical existing dwellings, so these have been modelled for eight dwelling types, using a heroic set of assumptions, with the BRE figure of 120 tonnes taken to be the average mass of an existing home. Data on waste disposal routes for all construction and demolition waste were used as a proxy for waste from housing since no detailed breakdown was available.

Because of the high levels of uncertainty about input data, no attempt has been made to estimate total quantities of waste over the whole time period to 2050 under each of the scenarios. The margins of error on the input variables make such an exercise potentially misleading: data with large annual errors multiplied over 45 years can only give unreliable results. Instead, the waste calculations are presented as a comparative snapshot under each of the three scenarios, indicated by the relative heights of the bars (Figure 9), with different proportions of materials assigned to the categories of re-use, recycling and landfill. In this context, re-use is taken to mean separation of a building element so that it can perform the same purpose (or a very similar purpose) in a new building without substantial transformation. So, for example, a wooden beam taken from the roof of a demolished house and re-used as a beam or other structural timber in a new house would be an example of re-use. Recycling includes any use of a product that requires substantial re-processing of the material. Often this will be to a product with a lower specification than the original because it is broken, contaminated or otherwise unusable for its original (high-specification) purpose. So, where a roof beam is separated from a demolished building and burned or chipped, that would count as recycling. Recycling also includes 'up-cycling', where a low-grade waste material can be re-processed into a high-specification product (eg broken glass used in insulation).

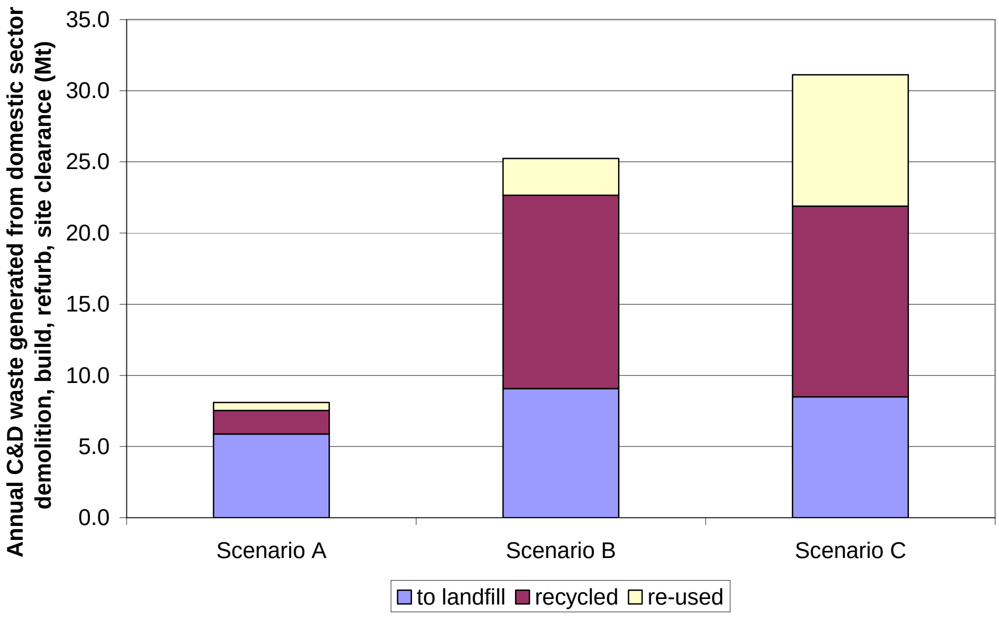

Figure 9 Indicative annual waste disposal quantities and disposal routes, Scenarios A, B & C

The total amount of waste generated would increase significantly with an accelerated programme of renewal and refurbishment (up 312% in Scenario B and 384% in Scenario C). Scenario A is broadly equivalent to current practice, with around 70% of waste from domestic sites going to landfill. Under Scenario B, current good practice is taken as the standard (promoting recycling rather than landfill) with 35% going to landfill, while Scenario C assumes that a concerted effort is made to re-use materials, with a secondary preference for recycling over landfill. The amount of change implicit in Scenario C is very large, with widespread de-construction of housing being the norm, using techniques such as cleaning mortar from bricks and storing them for re-use. This has implications for the creation of appropriate markets, trading and storage facilities for the re-used and recycled materials.

The burden on landfill decreases as a proportion of waste in scenarios B and C, but the absolute quantity of landfilled waste increases in both, compared to scenario A.
This comparison shows the importance of better waste management practices in reducing the waste impacts, but it also shows that increases in waste are an inevitable consequence of housing renewal and refurbishment. This is one area where improving the efficiency of the UK housing stock will have a negative environmental impact.

4. Challenges and opportunities

4.1. Housing – refurbishment

The existing housing stock represents one of the most significant challenges, particularly given that over 85% of current dwellings are likely to be still standing in 50 years time. It is these houses that will determine patterns of production (in terms of setting expectations for new buildings) and consumption. The housing sector possesses a great deal of stability, typified by a low stock turnover and the static nature of a building, and so social and technical change tends to occur slowly. Significant refurbishment of existing dwellings to a standard beyond current Building Regulations is crucial in reducing emissions, as well as minimising water use. Reducing the environmental impact of housing requires that these refurbishments are undertaken sustainably, with attention paid to the materials used and the quantities of waste produced with an emphasis on re-use and recycling.

The actors involved in refurbishment are many and varied. Home-owners (who may not live in the home), are key actors in bringing about change – they have to be prepared to alter the home which they own, whether as a householder or landlord. The split incentive within the rental sector, where the landlord receives no direct benefit of any alterations, is a further challenge. Social housing providers could play a key role in providing leverage for the refurbishment market as a whole, through achieving economies of scale with procurement.

Other important actors with regards to refurbishment are the builders and tradesmen who carry out the work. The nature of the industry is a large number of small businesses, quite often sole-traders and locally based, rather than the big multi-national companies that typify the mainstream construction industry. This small scale nature presents a particular challenge when attempting to bring about change. However, each builder, electrician and plumber has a significant role to play in informing and influencing the householder about the various technologies available. In many cases, they are responsible for specifying and ordering the products, rather than the householder themselves. The householder is generally looking for a certain level of service, eg a new bathroom suite or an insulated loft, and would not necessarily know, or even have access to information on the range and performance of the different technologies available.

The majority of technologies necessary to carry out the refurbishments are already available. Some, such as solid wall insulation have not been widely adopted and are relatively costly and disruptive. Others, such as cavity wall insulation are more firmly established, but have not yet become fully mainstream. Whilst there has been some uptake of measures such as loft and cavity wall insulation in response to various grants (Shorrock *et al* 2005), progress is still slower than is necessary. Likewise, in the water sector, efficient technologies are available at little or no cost premium, requiring minimal behavioural change (aside from their installation) but are still to be widely adopted. A mandatory label scheme could provide the necessary information to enable people to choose such products on the grounds of the environmental impacts.

Refurbishment of existing dwellings is hugely challenging. Homeowners are not generally aware of the opportunities to reduce running costs, nor how to go about delivering them, nor do they perceive this use of capital as a priority over other expenditure. The point at which a property is purchased or rented is a key opportunity to demonstrate what needs doing and the Home Information Pack (due to be introduced in 2007) has the potential to be a useful tool. However, to be most effective, it requires linking to a financial incentive (stamp duty or income tax rebates) and for the Government to work with the mortgage industry to promote extensions to mortgages to fund the work. There is a mindset that single measures (like loft insulation or cavity wall insulation) are sufficient. To achieve a 60% reduction in carbon emissions requires a change in thinking, to refurbishing the whole envelope together, including not only cavities and lofts, but windows, floors, all kinds of walls and airtightness. Underpinning this, as part of any major works (eg extensions or refurbishment), the Building Regulations should also require an upgrade of the rest of the house to meet a certain standard.

4.2. Housing – new build

Alongside refurbishment of the existing stock, the rate of new build needs to increase to address the current undersupply of housing and replace any dwellings demolished. An additional 6.8 million dwellings are required by 2050 as a minimum to meet projected demand. It is essential that these new dwellings are built to an extremely high standard to provide ultra-low energy housing – by 2015, any new home must be built to close to zero heating demand, as typified by the BedZED development. New housing represents the ideal opportunity to build truly sustainable homes, with minimal environmental impact in both the construction process and in use, in terms of water, waste, materials and energy.

The mainstream new-build sector is different to the refurbishment market, with housing developers as the key actors, alongside architects, developers, planners and government. The public are not involved, although there are strong societal concerns about new housing construction, especially on greenfield sites. Designers and architects play a crucial role since many of the measures which aim to reduce environmental impacts need to be incorporated into the design of the house at an early stage. These measures cover the range of impacts from efficiency, LZCs and the stack effect (in relation to energy), to grey-water and rainwater harvesting systems, through to the provision of segregated bins for household waste and the size of the house in relation to land-use. Householders have little or no role in mainstream construction, aside from what the industry perceives to be ‘consumer demand’ – there is no easy route through which the householder can communicate their needs to the industry. Hence, this area requires a different approach in tackling the associated environmental impacts.

In contrast, the self-build niche, where most innovation in sustainable housing takes place, shares more similarities with the refurbishment sector – the owner is one of the main drivers with the employment of small-scale builders and tradesmen. The socio-technical context of the self-build niche, such as strong green values, ability to take risks and close connection between the client and the builder, is different to the mainstream housing socio-technical context and is therefore not easily transferable (Smith 2004). The Building Regulations can be seen as a way of adopting those practices that have sufficient flexibility to transfer between contexts, whereas a more ambitious approach would be to attempt to transform the mainstream socio-technical context itself (*ibid*) and engender stronger environmental values and methods within the conventional construction industry.

There are currently a number of different standards and voluntary codes in use for new build including Building Regulations, the draft Code for Sustainable Buildings, Ecohomes ratings and standards set by Passive House, BedZED, Energy Efficiency Partnership for Homes and the Association for Environment Conscious Building (AECB). Amongst these, the last four come close to the level required to deliver the necessary carbon reductions, whereas current Building Regulations are well below the standard necessary. Building Regulations have come to represent both a minimum and a maximum, with no incentive to innovate above this level. There is often weak enforcement and thus little likelihood of actually meeting these standards. Housing developers are resistant to changes in the regulations because there is often little motivation to try out and prove new techniques in advance of the standard. Changes in Building Regulations represent an unknown leap to developers, when their current product is relatively stable and yields a relatively predictable profit.

A more coherent approach is necessary, with the establishment of one clear system which incorporates the full range of environmental impacts and an explicit timetable for a rapid improvement in standards, detailing what is required in 2010, 2015 and 2020. This is essential to provide clear signals for industry in order to encourage appropriate investment and innovation. A move towards performance standards could provide a more flexible approach in terms of how the savings are delivered and would be effective in ensuring that the necessary reductions are achieved in practice. Tighter standards and proper enforcement are crucial, requiring sufficient numbers of trained and skilled Building Control Inspectors in place. Compliance would be encouraged through introducing a financial penalty for developers, or even preventing them from putting a property onto the market in the first place, if building performance does not meet the required standard.

The planning system has a key role to play in addressing the sustainability of new housing across the various environmental impacts, dealing with the important regional considerations relevant to land-use, water resources, landfill availability and location of renewables, both large-scale and micro. In particular, water demand management must be incorporated into the planning system to ensure appropriate measures are included before planning permission is granted – the industry still has the philosophy of 'predict and provide' and has not focused on the many demand management opportunities (Appendix C). In severe cases, lack of water resources should be a reason for planning refusal.

4.3. Housing – demolition

Demolition for energy reasons and new build (possibly at higher densities) has proven a challenging debate. Many people perceive this as an attack on heritage, but it does not have to result in a loss of architectural value. The main driver is to improve the efficiency of the stock, and thereby quality of life, as well as minimising overall land-use, with listed buildings and those in conservation areas remaining protected. There is also the question of the energy implications of demolition and rebuild compared with refurbishment. Energy in use far outweighs the embodied energy of the existing stock over the average lifetime of the dwellings, but there is only an energy benefit from demolition and re-build provided that the replacement dwelling is built to a high enough standard. There is a strong need for a rational housing and energy debate that addresses such issues.

However, with the majority of homes in owner occupation it is hard to see the sort of incentives that would encourage this group to demolish and rebuild (other than on large plots where densification is already cost effective). It is an example of how the social infrastructure (tenure patterns, aesthetic considerations) influences technical potential. It is also hard, on cost effectiveness grounds to justify demolition and rebuild – if the cost of rebuild were invested in energy efficiency and LZC, much could be achieved. Additional reasons for pointing to a need for higher demolition rates are two-fold, first to allow building at higher densities to protect greenfield sites, and second, because, at present rates of replacement the stock would on average have to last around 1300 years. The consequent increase in waste arisings will require appropriate waste management strategies to be set in place to reduce overall waste production, encourage re-use and recycling and minimise waste to landfill.

4.4. Lights and appliances

The lights and appliances within both new and existing dwellings represent an area where significant savings in energy and water could be made but also where major growth could occur. The appliance sector is distinct from the housing and construction market, with the key actors being the manufacturers (European and international), retailers and householders. It is in this sector that the market transformation approach has been traditionally applied. The market benefits from a relatively fast turnover in the stock, with the average product lasting between 5 to 15 years depending on the appliance type (eg refrigeration, consumer electronics) and so is not seen as a long-term investment in the way that houses are. This means that savings can be achieved more quickly, but conversely growth can occur rapidly if appropriate policy is not put in place.

Policy on traded goods has to be applied at the level of the single market, with strong product policy at the European level supported by national governments being crucial. Progress has certainly been made within the energy sector in terms of improvements in efficiency, with the combination of the European energy label and minimum standards helping shift the market towards more efficient appliances (Schiellerup 2001; Boardman 2004). However, progress is limited and slow, and despite such advances, energy consumption in lights and appliances has actually increased over the last 30 years (Boardman *et al* 2005). This is due to both an increase in the number of appliances owned by the average household as well as some take-back of efficiency gains in increased standards, for instance, larger refrigerators. These are both trends which are working against a move towards greater sufficiency and sustainability.

Hence, one of the key issues in the appliance sector is how to encourage householders to own smaller and possibly fewer appliances. Switching the emphasis from energy efficiency to energy conservation may be part of the answer – this could be reinforced by a change in the energy label so that it is based on absolute consumption rather than relative values, eg the current metric of kWh/litre favours larger refrigeration products. A framework such as personal carbon trading[8] would help bring about a societal shift and create demand for lower energy appliances. It would also discourage the financial savings made through energy efficiency being spent on carbon-intensive options such as additional flights.

The market transformation approach adopted by the UK Government to date has been somewhat timid and piecemeal, with the complete range of energy efficiency policies not being used to full effect and prompted almost exclusively by Directives from the European Commission. Individual legislative acts have been useful, but poorly co-ordinated. For instance, the voluntary agreement on televisions and video-cassette recorders covered standby consumption, but not electricity use in the on-mode, which could be two orders of magnitude greater. This enabled the manufacturers to exploit the omission and produce the profligate plasma TVs. Labels on other products were effective at first but have not been updated appropriately to reflect the range of products on the market, making it difficult for people to easily identify those that are low-energy. There has also been a move away from mandatory processes towards voluntary agreements, weakening the impact, raising the question as to whether this shift has been beneficial for society as a whole. The combination of voluntary processes and poor ability to differentiate products has failed to support innovation from manufacturers, providing little incentive to introduce key technologies, such as LED lighting and Vacuum Insulated Panels for refrigerators. There are also opportunities for savings from fuel switching, moving from electric to gas cooking and tumble dryers, which are currently overlooked.

In the US, there are in excess of 43 product standards, and regulation has given manufacturers a clear direction of change. The development of new, efficient technologies requires a strategic framework with a long term view to develop and encourage innovation. The European Energy Using Products Directive and Energy Services Directive re1present an opportunity to create such a framework using a more

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[8] Personal carbon trading is synonymous with personal carbon allowances and domestic tradable quotas

holistic approach, although first indications are that the scale of the challenge – the target of a 60% carbon reduction by 2050 has not been grasped.

4.5. Low and Zero Carbon technologies

Low and Zero Carbon technologies form a crucial part of the carbon reduction strategies modelled in Scenarios B and C, illustrating the possible mix of technologies that could be employed. Depending on how technology and economics develop, it may be that a different mix becomes more viable. It is the combination of significant installation of LZC along with demand reduction, refurbishment and demolition as part of a clear and co-ordinated strategy that is essential to achieving a low-carbon housing stock. As well as providing a low carbon source of energy, LZC also represent a move towards more decentralised power generation, making energy generation and use more visible to householders. This in turn may lead to an increased awareness of energy use and encourage people to adopt more resource-conserving behaviour in general (SDC 2005b). Certain groups of people may actually be interested in investing in such technologies because they make a public statement of their values regardless of whether they are cost-effective or not (DTI 2005). These people are important early innovators in a wider process of socio-technical system change, helping to refine and encourage the development of early models of LZC technologies.

LZCs represent a portfolio of technologies – there is no one single solution, but a range of options to choose from which are appropriate in different types of homes and locations, determined by size, fuel availability (access to solar, wind, biomass) and density, amongst other factors. Some technologies work better in combinations than others. This variation demands a clear holistic strategy and explicit targets to provide a framework for industry to innovate and encourage diversity. Careful design and integration are essential to ensure the correct nature and capacity of the measure installed to achieve maximum benefit – it is not simply a case of bolting wind turbines and solar photovoltaics (PV) onto as many roofs as possible. Integration of LZCs is essential for both new build and refurbishment to deliver the necessary carbon reductions – planning policy and Building Regulations have a key role to play. Installation in new build is much easier from both a design and finance perspective, with LZCs representing a marginal cost that could be incorporated into the initial design. A high standard of new build combined with the installation of LZCs could achieve zero carbon emissions for new dwellings by 2020.

From a socio-technical perspective, the installation of LZCs presents arguably the greatest challenge, requiring a major shift in the nature of the supply industry and network operators, with consequences for the investment of capital. The industry has significant investment in the existing infrastructure and their interest is in retaining an income stream from electricity flowing through the network rather than managing a large number of small scale exporters of power. Policy support is needed for the development of new infrastructure, such as district heating networks, and to help overcome resistance to shared facilities as well as energy from waste (ie anaerobic digestion and pyrolysis).

In terms of financing the capital expenditure required, feed-in tariffs and capital grants are two possible options, accessed by the householder or an Energy Service Company (ESCo). Feed-in tariffs form an essentially self-financing system of support driven by the market price of electricity and have been successful in supporting the development of solar PV in Germany and Spain (Fouquet *et al* 2005). The emphasis in the UK has been on capital grants programmes to date, requiring an appropriate fund to be made available eg through general taxation rather than higher fuel prices. ESCos represent a possible mechanism for delivery of the technologies, with the company investing in the products in order to provide the customer with the energy service, thus avoiding major capital expenditure by the householder. ESCos are not straightforward to implement, requiring suppliers to change the nature of their businesses or new players to enter the market and customers to accept a change in the nature of their energy supply with a shift from buying units of gas and electricity over to long term service contracts.

There is an opportunity to develop niche markets in new build that could lead to wider socio-technical change:

- In new buildings a certain level of heating needs to be supplied anyway, so the cost is the marginal up-front cost of LZC over conventional heating
- Housing developers could out-source the entire provision of energy infrastructure to an ESCo, who could design, build, finance and operate the system
- Economies of scale can be achieved because of the combined size of new-build projects
- Design of the local network can maximise income, eg through ownership of the electricity infrastructure, an ESCo could sell any electricity exported direct to other households rather than the network and so would benefit from higher retail prices rather than selling at wholesale prices

There are currently few successful UK projects to draw on in either new build or refurbishment: demonstration is still needed, not only of technologies, but of appropriate management models. Significant progress has been made in other countries: for example, Germany has recently completed a programme of 100,000 solar roofs (Stubenrauch 2003), compared with the installation of just over 1,000 in the UK (EST 2005). And in Finland and Denmark, district heating schemes serve around half the population, whereas in the UK such schemes cover less than 0.1% of households.

4.6. Interactions

The modelling work has identified a number of crucial interactions between the various environmental impacts, which sometimes operate in opposite directions, highlighting some of the trade-offs that need to be considered in developing future policy.

4.6.1. Demand and supply

The interaction between national energy demand and the supply chain is reflected at the individual household level: the more efficient the products and low-energy the buildings and lifestyle, the less supply is needed and, importantly, the reverse: the more there are sources of supply, the less pressure there is to alter lifestyles and reduce demand. In Scenarios B and C, the emphasis is on demand reduction first, because this is the strategy that would lead to the lowest level of capital expenditure and running costs. There is considerable installation of LZCs, so that the subsequent demand has a minimal carbon impact. Even if the LZCs are not installed, the supply that has to be provided by a centralised system is minimised. It is recognised, however, that in the context of the current Energy Review there is significant political pressure to adopt a more supply-side, rather than demand-side, approach to meeting the UK's future energy needs (DTI 2006).

An alternative view would be perfectly feasible: to accept that large levels of LZCs are going to be installed and that once this has happened, the energy efficiency of the building and equipment becomes less significant – even quite high levels of demand can be met with a low carbon impact. A reluctance to demolish 80,000 properties a year could be offset by an early programme to install CHP. However, the CHP, heat pump and biomass would need to be larger or have to work harder, implying higher capital costs for larger kit and higher running costs from use of more gas, electricity and wood, with consequent impacts on resource use. The safest approach is to address both demand reduction and low-carbon supply and go for the maximum of everything (heat loss reductions, demolitions, LZC installations, appliance standards), thus providing a cushion for inevitable slippage, as in Scenario C.

4.6.2. Demolition

Decisions on demolition rate affect land-use, energy and waste. Increasing demolition can be beneficial in reducing energy and land-use, but will inevitably result in an increase in waste arisings. For the purposes of the UKDCM, demolition is assumed to be any building work which involves demolishing and rebuilding 50% or more of the external walls. The UKDCM assumes that demolition occurs equally across all dwelling types and ages, since this has been the general historic trend[9]. However, it could be possible to take a more targeted approach with a number of different demolition strategies conceivable. Each of the strategies discussed below share some key underlying assumptions:

- There will be an increase in the demand for housing, rising to 31.8 million households in 2050 (Section 3.2). Therefore, any existing properties that are demolished must be replaced to maintain the levels in the existing stock in order to meet projected demand.
- For there to be a net reduction in energy and carbon terms, the demolished properties must be replaced with homes built to an extremely high standard – far beyond current building standards.
- Ideally the houses would be rebuilt at higher densities wherever possible to minimise the total amount of greenfield land required for new housing developments.
- Central to any demolition strategy there must be an appreciation of the consequences for construction and demolition waste, with appropriate measures put in place to minimise the impact on landfill and encourage greater re-use and recycling.

The particular demolition strategy chosen will depend on the primary motivation – some strategies will achieve the same result even if the main objective is different. For instance:

- **Energy consumption.** If the aim is to reduce energy consumption of the housing stock, demolition could be targeted to remove the highest consuming dwellings. These could include both the least efficient houses (those that cannot be refurbished to a high enough standard) and also larger, possibly more efficient dwellings (which consume large amounts of energy due to their size). These dwellings are then replaced with dwellings built to an extremely high standard. There could also be some alleviation of fuel poverty through demolition of the least efficient dwellings.
- **Fuel poverty.** If the primary motivation was to eliminate fuel poverty, the focus for demolition would be on, for example, high density, inefficient, old (pre-1919) properties in urban centres, as well as many flats built in the second half of the 20th century. The replacement dwellings would be more efficient but most likely built at similar high densities, and so the impact on land-use may be minimal.
- **Land-use.** If minimisation of greenfield land-take was the main focus, then demolition would be concentrated on areas of low density, with larger houses or dwellings on a large plot of land. Demolition of these buildings would release land for development at much higher densities. This also represents an opportunity to maximise land use in developed areas, with the added advantage that services and infrastructure are already provided, therefore requiring less land in total compared to a completely new development on a greenfield site. There would also be a consequent energy benefit through building replacement dwellings to a higher standard. The impact on fuel poverty is uncertain, but possibly minimal since the houses demolished would be unlikely to be concentrated in fuel poor areas. Adopting a strategy of always building replacement dwellings at a higher density would help minimise greenfield take. It is, of course, vital that higher density developments are carefully planned to ensure both their sustainability and appeal to householders – good design and the provision of appropriate infrastructure and amenities are important to quality of life.
- **Minimise demolition.** If the aim was to minimise the amount of demolition, whether to minimise waste or preserve the existing stock, the implication would be that a significant amount more would need to done in other areas if the carbon reductions

[9] Listed buildings are assumed to be exempt from demolition

estimated under Scenarios B and C are to be achieved. Refurbishment of the existing stock would have to be to a greater extent and numbers of Low and Zero Carbon technologies would also have to be increased beyond those assumed in each scenario. Neither of these are trivial matters.

- **Preservation of heritage buildings.** Heritage buildings are likely to be amongst some of the least efficient within the housing stock. Therefore, avoiding demolition of such dwellings, as with minimising demolition, means that more will need to be done in other areas if the 60% target is to be reached. Alternatively, if it is the external appearance that is particularly important, one option could be to retain the façade and demolish the entire building behind, replacing it with an ultra low-energy building. This has consequences in terms of limitations on width and height of the replacement building and may also limit the scope for densification of the redevelopment, with associated implications for land-use.

4.6.3. Landfill

Landfill space is becoming scarce. At 2001 rates of disposal, the Environment Agency estimates that there are 6.9 years of landfill remaining in England, although this varies between regions from 4.5 years in the East of England to 8.2 years in the West Midlands (Environment Agency 2005). Increasing the rate of demolition will increase the amount of construction and demolition waste produced. The construction of new homes and increasing refurbishment levels will also increase waste arisings. Therefore whatever the balance of demolition, new build and refurbishment into the future, the amount of waste produced is set to rise. The waste management strategy adopted is crucial in determining how this waste is dealt with. Increasing the levels of re-use and recycling of materials will minimise the amount of landfill required and thereby reduce the amount of land used for this purpose.

The need for greater levels of re-use and recycling has consequences for the materials used in construction. In particular, over-strong cement mortars make it much more difficult to re-use materials: because the mortar is harder than the brick, the bricks are likely to break when trying to remove the old mortar. Significant re-use of building materials would require new on-site practices, better infrastructure for the storage of secondary materials and a shift towards specification of re-used materials in building design.

4.7. Opposing trends

There are a number of trends within society, policy and embedded in the existing infrastructure that tend to work against the increased sustainability of housing. Such trends help to explain why progress is slow and highlights how existing socio-technical frameworks may be acting to reinforce this lack of change and consequently where action could be focused. Some areas, particularly within social trends, are not amenable to change through policy but it is important to acknowledge the role they play in influencing consumption. The list presented here is not exhaustive but intended to illustrate some of the key issues identified through the research undertaken for this study.

4.7.1. Social trends

Social trends are probably the hardest to influence and are generally taken as given in the modelling work undertaken. These include:

- **Household numbers.** One of the main reasons for increased resource consumption is the growth in household numbers as a result of increasing population and declining household size. This is partly driven by the growth in people Living-Apart-but-Together (LATs) – around two million men and women have a partner living elsewhere (though not necessarily alone). Social policy cannot easily (if at all) influence such trends.

- **Under-occupation** is a related issue, because of elderly people continuing to live in the family home, as well as young people living on their own: there are over three million properties in England of an average size of 71m^2 lived in by just one elderly person (ODPM 2003). Moving people out of their family homes is an emotive issue, but a focus on providing them with a clear choice of good quality, energy efficient, smaller and convenient properties in town centres might be effective.
- **Temperatures.** The current trend appears to be towards ever warmer homes in winter and cooler in summer – temperatures of 23°C+ are now being discussed, whereas previously 21°C was thought to be the likely maximum in winter. Significant savings could be achieved by keeping temperatures below a maximum threshold but this requires behavioural rather than technological change, with people prepared to turn down their thermostats and wear warmer clothing indoors. In terms of cooling, air conditioning is being installed in new 'luxury' developments and the demand for electrically-driven cooling (fans and portable air conditioners) is likely to increase unless policies are developed to prevent summer overheating in existing buildings.

4.7.2. Infrastructure

The correct physical and social infrastructure is crucial in setting the right framework to encourage and ensure sustainability throughout the system.

- **Distributed generation.** The electricity system is still conceptualised around centralised plant, with many large commercial companies interested in maintaining this infrastructure. Redesign of the grid is necessary to support LZC technologies. Currently, the tariff for electricity sold back to the grid is extremely low, reflecting the high cost of managing small amounts of power but it does not reflect the importance of the contribution to the system from micro-generation (eg micro-CHP would contribute significantly to peak electricity load and avoid investment in both generating plant and distribution equipment).
- **Energy liberalisation** ends up with an under-regulated or inappropriately incentivised oligopoly. The dominant model of energy supply is a handful of players, each spreading the cost of metering, billing and settlement over several million customers. This represents a significant barrier for small new entrants to the market, eg Local Authorities, because the cost of their systems would be spread across only a few thousand customers, making it difficult for them to compete.
- **Financing system**. The positive benefits of green buildings are not currently included in the valuation and mortgage system – the standard approach does not address the right issues and so the benefits are overlooked – so there is a need to change the system first (RICS 2005).

4.7.3. Technology

There are many important trends associated with technology, both positive and negative, but the following represent examples of where policy could take a proactive approach to ensure that progress is made in a sustainable direction:

- **Integrated renewables**. Poor design, specification and maintenance of integrated renewables can mean that they do not supply to specification and potential investors are put off. Early failure of new technologies can dent consumer confidence and have a long term impact on uptake (eg early experience with compact fluorescent lamps). This also links in with the skills and training agenda, with a need for accredited installers to be of a high standard, and suitable infrastructure support for distributed generation.
- **Over-consumption**. At present, there is nothing to stop manufacturers making and marketing unnecessary/profligate appliances; consumers are unconstrained and often uninformed and do not know what energy demand they are buying along with a new appliance. Sustainability issues are not central to businesses and decision-making, although things would improve if corporate social responsibility is strengthened.

Another approach would be to require all products to be labelled with their energy consumption (similar to the requirement to carry a CE mark) before they can be marketed.

4.7.4. Housing and construction

Housing is an atypical consumer good – durable, with high cost and low turnover (Lovell 2005) and therefore change in this sector is slow. There are a number of established trends that are working against increased sustainability:

- **Architectural heritage**. There are obvious aesthetic and cultural benefits from preserving architectural heritage, but it may be that this is taken too far in the extent (numbers of properties) protected and refusal in many areas to allow solar thermal systems, PV tiles, etc. on roofs. Heritage properties may be hard to refurbish to bring up to the necessary standard, but the strong regulatory framework for preserving heritage is not currently matched by strong policies on the mitigation of climate change impacts.
- **Appropriate construction**. There is no clear link between social trends and new construction standards: much of recent new build is for ‘typical’ families, whereas the growth is in one or two-person households. The excess space results in wasted heat, room for additional appliances and takes up more land. However, there are signs that this trend is reversing with a substantial increase in the proportion of flats being built in the last few years (NHBC 2005).
- **Communication**. The construction industry has no direct dealing with the end-user – there is no easy route for householders to communicate what they want to builders. Builders are building in a vacuum.
- **Poor construction standards and enforcement of regulations**, including poor quality of work, corner-cutting and non-compliance with Building Regulations, result in the savings expected from new regulations not being achieved. This also links with the skills and training agenda – a lack of well-trained Building Control Inspectors leads to poor policing of building standards.
- **Thermal mass.** There is a risk of moving towards low thermal mass, eg with some Modern Methods of Construction, whereas high thermal mass may help reduce the likelihood of overheating in summer in a warming climate.
- **Incentives for innovation.** There is a lack of incentives, particularly financial, for really good, innovative practice with new buildings, whereas this would be the way to encourage niche developments under a traditional market transformation approach.
- **Labelling.** Policy is increasingly based on predicted and not actual consumption, with most energy audits (eg SAP – Standard Assessment Procedure) only covering space and water heating. Too often, energy use in lights and appliances is not included, as in the case of the new carbon standards in Building Regulations. The reasoning is that lights and appliances are specific to the occupant, but the net effect is that the efficiency focus stays on the same uses and lets electricity growth in lights and appliances continue without attention.
- **Market failures.** Housing shortages (and high price inflation) make a market transformation approach ineffective: householders will not be able to differentiate on the grounds of energy performance until there is more to choose from.

4.8. Society and policy

The role of society in reducing the environmental impact of housing can sometimes be overlooked in estimates of savings where the focus is on technology or economics, rather than considering the wider interactions with society. Whilst there is general consensus that the necessary technologies are available, the failure to address the socio-technical context may be one reason why the savings identified are not being achieved in practice. Predictions of environmental benefits can fail to materialise as a result of unexpected behavioural and social factors. For instance, if a conservatory is unheated it acts as a sun-trap, pre-warming air for the rest of the house and so, in theory, helps conserve fuel. In practice, many people choose to heat their conservatory and use it as an additional living room. The heat loss through the glass walls and roof is high, resulting in a significant increase in energy consumption (Oreszczyn 1993). More thought needs to be given to what the future might look like and the forms of social re-alignment that are required to achieve any technological vision (Shove 1998), with more perceptive analysis and policies which recognise the role that energy services play in people's lives. The modelling work undertaken for this study has aimed to address some of these issues. There needs to be a re-framing of the debate, whereby greater emphasis is placed on the social contexts within which decisions and policies are made. This is by no means straightforward: the number of different socio-technical systems is large and varied, whether at an individual, household or institutional level, and these systems in themselves are dynamic – for example, priorities change in times of recession compared with times of boom (Guy 1994).

There is a fundamental need for a shift throughout society, including householders, industry and policy-makers, towards greater sustainability and resource consciousness. From an energy perspective, the emphasis has to be on reducing carbon emissions. The societal landscape therefore has to incorporate concern about carbon with the desire and opportunity to address levels of consumption. Policy must recognise the potentially opposing trends within society which may work against reducing consumption and sufficiency and be proactive in mitigating against such patterns. Whilst it is impossible for policy to address the range of different socio-technical contexts at an individual level, it could aim to set an appropriate framework in place which embeds these concepts within the social landscape. Mandatory personal carbon trading (PCT) represents one such framework within which there is flexibility for householders to choose how they wish to use their carbon, depending upon their personal situation and values. There is still freedom of choice, but within certain constraints, and the emphasis is on sufficiency rather than increasing consumption. In one sense it is an enabling tool to allow people to live within the means of the world's resources. PCT would help stimulate innovation in low-carbon products and services. As with product policy, people will need information on which to base their actions and some kind of benchmark to assess progress. Existing measures such as electricity disclosure and the car label, with details on the amount of carbon produced, are working to reinforce this context.

The impact of generic policy measures like PCT would be strongly influenced by the availability of better metering and informative billing, with comparative and monthly information, as well as improved product information with wider labelling of appliances and buildings and information and advice at the time of a decision. If a person does not know the energy use of alternative choices or the resulting impact on their consumption, the energy implication of their choice is little better than random, or driven by another factor such as purchase price.

Socio-technical system theory suggests that change needs to take place at a number of different scales (Appendix B): in combination with strong European and national frameworks and legislation, there is a key role for local and regional targets and strategies in developing change and innovation within small niches. At a decentralised level there can be a greater appreciation of the particular social landscapes which are likely to vary between different areas, therefore allowing more socially viable strategies to be developed. The strong regulatory and policy framework can then support the translation of these ideas and technologies into the mainstream.

5. Conclusions

The environmental impact of UK housing is much greater than it need be. This results from misjudgements about the priorities of society, low levels of government attention and an industry without the right framework of incentives. None of the components of a virtuous circle have been successfully implemented, let alone brought together. The net effect is that people have no clear incentive to act and few real opportunities to be environmentally-friendly. This is reinforced by the perception amongst manufacturers, retailers and housebuilders that the British public do not care about energy efficiency and resource consumption. Shops often stock the least efficient models. The Building Regulations are set to a lower standard than in other Member States at the same latitude, for instance Germany and Sweden. Meanwhile, most people do not even realize the amount of energy and water they are using, let alone wasting, or the quantity of waste they are responsible for – both through the creation of the building fabric and their day-to-day lifestyle.

The conclusions here focus on understanding energy decision-making, both because this is the ECI's area of expertise and because it illuminates the potential for other resources, notably water. The legacy of energy inefficient buildings has been combined with a minimalist approach to policy intervention, partly because of:

- A misplaced belief that economic rationality would cause people to invest in greater energy efficiency and Government's failure to respond when these actions have not occurred.
- Linked to this is a focus on reducing the cost of energy for householders through market liberalisation. This has resulted in fuel expenditure averaging around 3% of the weekly budget in 2004-5 (ONS 2006), so the importance of saving some of this money becomes negligible.
- Recent evidence demonstrated that consumers routinely over-estimate the cost of an energy-efficiency improvement (for instance cavity wall insulation) and under-estimate the savings (Oxera 2006). If a payback was calculated on this basis, it would be grossly inaccurate.
- The recent price increases have pushed household gas costs up by 70% cumulatively since 2002 and electricity by a smaller amount. This will cause considerable hardship for the poor, but may still not lever the rich into more energy efficiency investments.

5.1. UK Government policy

So, what hope for the future? In the Energy White Paper (DTI 2003), the Government identified renewable energy and energy efficiency as the two primary policy approaches for the near future, and then did virtually nothing to support their progress. There has been no sense of urgency demonstrated by the Government, except for the recent decision to hold another Energy Review.

The current Energy Review does provide the opportunity to compare the savings that could be made through demand reduction with the quantities of future sources of supply. Most of the debate is about electricity and whether there is a need for new nuclear power or carbon capture and storage. In reality, a strong, proactive, comprehensive approach to sustainable, low-carbon housing could remove the need for either in relation to the residential sector. But this would depend upon a Government that takes a comprehensive, proactive role in guiding consumers – a role that they have been reluctant to assume (SDC 2006b).

5.2. Question 1 – What framework?

If an overarching framework could be found for household energy use, this would simplify the number of policy interventions needed by Government. It would also make it easier to choose between additional supply and reduced demand. The major benefit of an overarching framework would be that it turns 25 million households into an asset – people working with the grain of policy – instead of a liability with a vast number of people making decisions independently and ignorant of their environmental impact. In order for people to join the carbon challenge, the policy framework needs to provide them with a clear indication of what they are attempting to achieve and how: it needs to give them 'agency'.

One possible option for an overarching framework that would bring together all aspects of energy use in the home is the introduction of personal carbon trading (PCT), taking a society-centred, rather than technology-centred, approach. Strong political and public support would be required to pass PCT into legislation and there will be significant challenges accompanying its introduction. Such a system would provide people with a reason for understanding their energy consumption and the resultant carbon emissions. Householders would quickly become carbon-literate and therefore be transformed into knowledgeable consumers who are prepared to demand low-energy products. Manufacturers would soon learn not to produce high-energy using equipment, as it would have limited sales. The benefits of PCT spread beyond the use of electricity and include all fuels used in the home, personal travel and flights. It would also help to combat fuel poverty, as low-income households who do not drive or fly are expected to have surplus carbon credits to sell. At the very least, PCT could serve to provoke useful debate about more integrated socio-technical policy options.

5.3. Question 2 – What boundaries?

One of the lessons that has emerged from this study is the importance of an holistic approach, providing an appreciation of the full range of interactions. The level of demolition impacts on greenfield land use, as well as total energy demand and waste production. Policy that is framed in terms of energy efficiency, rather than absolute energy consumption, permits the development of larger fridges, washing machines and houses. Reduced demand is needed rather than products which use more energy in the name of greater energy efficiency. Whilst it is more challenging to take a broad overview of the various environmental impacts, the breadth ensures greater confidence in the decisions made, helping to clarify the appropriate objectives, and prioritisation of these, along with an acknowledgement of the trade-offs involved.

The breadth also relates to the timeframe chosen. By looking ahead, for instance to 2050, the trajectory for action is clear and, therefore, the direction for policy. A near-term focus risks distorting priorities. For instance, incremental changes to the energy efficiency of a property would be seen as adequate, whereas in reality a whole-house assessment is needed with a decision to improve or demolish. Policy has been driven by an assumption that low fuel prices are desirable and will continue. When taking a longer term perspective, higher prices, either because of internalisation of external costs, or because of scarcity, seem much more probable. Societal decisions based on low prices now may come to be seen as fundamentally flawed.

5.4. Question 3 – When does it need to happen?

Although 2050 appears a long way off, this does not mean that action can be put off until tomorrow. The challenges of achieving a 60% reduction in carbon emissions from the UK housing stock should not be underestimated and steps need to be taken immediately to ensure that we are on course to meet this target. The policy process is slow: allowance needs to be made for time taken to reach agreement on the necessary standards and sufficient notice period for industry to prepare and adapt before policies take effect. Once standards are in place, this is not the end of the story – it takes time for the new technologies to penetrate the stock. The stock turnover rate varies from between 5 to 15 years for appliances, to around 100 years for replacing roofs and several hundreds of years for the houses themselves. Hence strong and far-sighted policies need to be implemented now to ensure that the savings are delivered within the next 50 years. Taking a longer-term view is also essential in providing clear signals to industry in terms of the direction in which they need to innovate: publishing a series of standards now for the next 10-15 years gives certainty and security to encourage investment and development along more sustainable pathways.

If a more stringent target is set beyond the 60% carbon reductions (as in Scenario C), this serves to highlight the immediacy of action necessary, with an emphasis on even stricter standards and greater support for new and emerging technologies such as fuel-cells and renewables-based LZC.

5.5. Question 4 – What role for local authorities?

With all the environmental impacts, it could be appropriate for local authorities to have a strong role. They are central to decisions on land use and waste disposal and there are further links between planning permission and energy and water use. For instance:

- Planning permission should take account the availability of water;
- Through planning permission, local authorities can require new buildings to include a certain percentage of on-site generation, as the London Borough of Merton has demonstrated;
- The density of development can be strongly influenced by the planning authority;
- Rates of demolition may need to be accelerated through compulsory purchase or planning incentives to increase density.

At the moment, the role of the individual tiers of government are not well-defined in relation to housing and energy strategy and this may be contributing to the lack of delivery.

5.6. Question 5 – What type of society?

The present debate, engendered by the Energy Review, is also about the type of society we wish to be creating. There would probably be a substantial difference by 2050 in the effects of the options open, that could be typified as centralised or a decentralised approaches.

The former focuses on centralised power provision (particularly electricity), through nuclear power stations and carbon capture and storage. Consumers continue to ‘flick the switch’ and use electricity, with little knowledge about how it is generated, or whether it is contributing to climate change. Responsibility for levels of demand are seen as the concern of the utilities or the government, not the household. Demand for energy use in the home continues to grow and energy efficiency improvements are quickly offset by purchases of more equipment. This may be the most likely route to scenario A.

The latter, the decentralised world, has achieved a high level of awareness and involvement by households, making it easier for them to take personal responsibility. They have reduced demand, through the refurbishment of their properties, have purchased LZCs and thus have a much better understanding of their patterns of consumption and associated costs. They know they are contributing to lower levels of climate change and are pleased about this. This future, partly through the impact of personal carbon trading, is the route that takes the UK to either Scenario B or C.

The delivery of low-carbon, sustainable housing and lifestyles requires a multitude of incremental changes by individuals, retailers, manufacturers, housebuilders and others. If the right context – the right socio-technical framework – can be found, then we can all be guided towards appropriate choices and reduce our impact on the planet.

References

Barker K (2004) *Review of housing supply. Delivering stability: securing our future housing needs. Final report – recommendations*. HM Treasury, London, UK. http://www.hm-treasury.gov.uk/media/0F2/D4/barker_review_report_494.pdf

Boardman B, Darby S, Killip G, Hinnells M, Jardine C, Palmer J, Sinden G (2005) *40% House*. ECI research report 31, Environmental Change Institute, University of Oxford, UK. http://www.eci.ox.ac.uk/lowercf/40house.html

Boardman B (2004) *Achieving energy efficiency through product policy: the UK experience.* Environmental Science and Policy 7(3), 165-176

DTI (2006) *Our energy challenge: securing clean, affordable energy for the long term.* Department of Trade and Industry, London, UK. http://www.dti.gov.uk/energy/review/energy_review_consultation.pdf

DTI (2005) *Potential for MicrogenerationStudy and Analysis.* Final Report, undertaken by Element Energy on behalf of Energy Saving Trust, Department of Trade and Industry, London, UK.
www.dti.gov.uk/energy/consultations/pdfs/microgeneration-est-report.pdf

DTI (2003) *Our energy future – creating a low-carbon economy*. Energy White Paper. Department of Trade and Industry, The Stationery Office, London, UK. http://www.dti.gov.uk/energy/whitepaper/ourenergyfuture.pdf

Entec, Richard Hodkinson Consultancy & eftec (2004) *Study into the environmental impacts of increasing the supply of housing in the UK.* Report to Defra, Entec UK Ltd, Leamington Spa, UK.

Environment Agency (2005) *Local waste interrogator*, accessed online at http://www.environment-agency.gov.uk/subjects/waste/1031954/315439/170850/689218/?lang=_e

EST (2005) *Major PV demonstration programme – project data.* Energy Saving Trust, London, UK.
http://www.est.org.uk/uploads/documents/housingbuildings/InfoForInstallers23_9_05.pdf

EST (2003) *The UK Potential for Community Combined Heat & Power*. Energy Saving Trust, London, UK.

Fouquet D, Grotz C, Swain J & Vassilakos N (2005) *Reflections on a possible unified eu financial support scheme for renewable energy systems (RES): a comparison of minimum-price and quota systems and an analysis of market conditions*. European Energies Renewable Foundation and Worldwatch Institute, Brussels & Washington DC

Graham S & Marvin S (2001) *Splintering urbanism: networked infrastructures, technological mobilities and the urban condition.* Routledge, London, UK.

Guy S (1994) *Developing alternatives: energy, offices and the environment.* Paper presented at 'The Cutting Edge' Conference of the Society of Property Reseerachers, City University, 3 September

Hinchliffe S (1996) *Technology, power and space - the means and ends of geographies of technology*. Environment and Planning D: Society and Space 14 659-682

Hinnells M (2005) *The cost of a 60% cut in CO2 emissions from homes: what do experience curves tell us?* Paper to British Institute of Energy Economics Conference (www.biee.org), Oxford, UK.

Hitchen R (2004) *The UK heat pump market*. IEA Heat Pump Centre Newsletter 22 (4). http://www.heatpumpcentre.org

Horton B (2005) *Sustainable Homes – the financial and environmental benefits.* Environment Agency, Bristol, UK.

Hughes T P (1987) *The Evolution of Large Technological Systems*, Eds W E Bijker, T P Hughes and T J Pinch, in 'The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology', MIT Press, Cambridge, pp. 51-82

ICE & RPA (2005) *Quantification of the potential energy from residuals (EfR) in the UK*. Undertaken by Oakdene Hollins on behalf of Institute of Civil Engineers and Renewable Power Association, London UK.

James N & Desai P (2003) *One planet living in the Thames Gateway*. Bioregional Development Group, London, UK.

Jones, Craig (2005) *personal communication.* University of Bath

Joosten L, de Jonge S and Boonstra C (2004) *Gallions Ecopark Monitoring*. DHV Bouw en Industrie client report for Gallions Ecopark, November 2004 (version 1)

Kemp R (1994) *Technology and the Transition to Environmental Sustainability*. Futures 26 1023-1046

Kemp R, Schot J W & Hoogma R (1998) *Regime shifts to sustainability through processes of niche formation: the approach of Strategic Niche Management*. Technology Analysis and Strategic Management 10 175-195

Lovell H (2005) *Supply and demand for low energy housing in the UK: insights from a science and technology studies approach.* Housing Studies, Vol. 20, No. 5, 815-829

NHBC (2005) *New house building statistics*. National House-Building Council, Amersham, UK

NLUD (2004) *National Land Use Database of Previously Developed Land*. English Partnership Regional Summaries
www.nlud.org.uk

ODPM (2005a) *A sustainability impact study of additional housing scenarios in England.* Office of the Deputy Prime Minister, London, UK.
http://www.odpm.gov.uk/index.asp?id=1162086

ODPM (2005b) *Planning Policy Guidance 3: Housing.* Office of the Deputy Prime Minister, London, UK.
http://www.odpm.gov.uk/index.asp?id=1143941

ODPM (2003) *English House Condition Survey 2001*. Office of the Deputy Prime Minister, London, UK.

ONS (2006) *Family Spending 2004-05.* Office of National Statistics, London, UK.
http://www.statistics.gov.uk/downloads/theme_social/Family_Spending_2004-05/FS04-05.pdf

Oreszczyn T (1993) *The energy duality of conservatory use*. Proceedings of the 3rd European Conference of Architecture: Solar Energy in Architecture and Planning, pp 17-21, Florence, Italy.

Oxera (2006) *Policies for energy efficiency in the UK household sector.* Report prepared for Defra, Oxera Consulting Ltd, Oxford, UK.

Passivhaus Institut website http://www.passivehouse.com/English/PassiveH.HTM, accessed March 2006

RCEP (2004) *Biomass as a renewable energy source*. Royal Commission on Environmental Pollution Special Report.
http://www.rcep.org.uk/bioreport.htm

RICS (2005) *Green value: green buildings, growing assets.* Royal Institute of Chartered Surveyors, London, UK.

Schiellerup P (2001) *An examination of the effectiveness of the EU minimum standard on cold appliances: the British case.* European Conference for an Energy Efficiency Economy, Mandelieu, France
http://www.eceee.org/library_links/proceedings/2001/abstract/Panel1/01p1_1_024.lasso

Schot JW, Hoogma R & Elzen B (1994) *Strategies for Shifting Technological Systems : the case of the automobile system*. Futures, pp.1060-1076

SDC (2006a) *'Stocktake': delivering improvements to existing housing*. Sustainable Development Commission, London, UK.

SDC (2006b) *The role of nuclear power in a low carbon economy.* Sustainable Development Commission, London, UK.

SDC (2005a) *Sustainable buildings – the challenge of the existing stock*. Sustainable Development Commission, London, UK.

SDC (2005b) *Seeing the light: the impact of micro-generation on the way we use energy*. Sustainable Development Commission , London, UK.

Shorrock L, Henderson J and Utley J (2005) *Reducing carbon emissions from the UK housing stock.* Building Research Establishment, Watford, UK.

Shove E, Lutzenhiser L, Hackett B, Guy S & Wilhite H, (1998) *Energy and Social Systems*. Eds. S Rayner and E Maltne in Human Choice and Climate Change (Ohio, Batelie Press) pp. 201-234

Shove E (1998) *Gaps, barriers and conceptual chasms: theories of technology transfer and energy in buildings.* Energy Policy Vol. 26, No.15, pp 1105-1112

Smith A (2004) *Governance lessons from green niches: the case of eco-housing.* ESRC workshop on Governance, Technology and Sustainability, Open University, Milton Keynes

Smith A, (2002) *Transforming Technological Regimes for Sustainable Development: a role for Alternative Technology niches?* SPRU, Sussex University, UK.

Stubenrauch F (2003) *National survey report of PV power applications in Germany*. Prepared on behalf of BMU – German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, International Energy Agency.
http://www.oja-services.nl/iea-pvps/nsr03/download/deu.pdf

Sustainable Homes (1999) *Embodied energy in residential property development: a guide for Registered Social Landlords*. Sustainable Homes, Hastoe Housing Association, Middlesex, UK.
http://www.sustainablehomes.co.uk/EMBENG.PDF

Szejnwald Brown H, Vergragt P, Green K & Berchicci L (2003) *Learning for sustainability transition through bounded socio-technical experiments in personal mobility*. Technology Analysis & Strategic Management 15 291-316

Unruh G C (2002) *Escaping carbon lock-in.* Energy Policy 30 317-326

XCO2 (2002) *Insulation for Sustainability: a guide.* A research study by XCO2 for Bing (Federation of European Rigid Polyurethane Foam Associations)