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Executive Summary

This report consists of an evidence review and recommendations on the future of housing (and some aspects of energy) to support the Scottish Government's second Report on Policies and Proposals (RPP2). The study was commissioned by SNIFFER on behalf of ClimateXChange Scotland, and conducted by the Dept of Construction & Surveying at Glasgow Caledonian University. A Summary for Policymakers, referenced to this report, is available as a separate document.

The purposes of this report are to:

- Identify what Scotland's housing stock is expected to look like (in terms of energy demand) by 2020 assuming the emissions savings anticipated in delivery of Homes and Communities policies and proposals in RPP1.
- Scope how residents may be expected to have adapted to the low carbon agenda in their homes over the 10 years (2010 to 2020), taking into account drivers such as the UK and Scottish programmes, the rising cost of energy, growing awareness of climate issues and hassle factors.
- Describe and prioritise potential abatement policies, approaches or measures that could be implemented 2020-2030 and their expected impact.
- Describe key remaining abatement priorities in the housing sector after 2030.

Sections 1 to 3 set the context for this report, i.e. the trajectories set out under RPP1, trends in household energy use, and the composition of the Scottish housing stock.

Section 4 addresses the current policies and proposals for reducing energy demand and emissions from Scottish households. These are split into devolved and non-devolved issues, plus some common concerns, with some comment on those areas where greater devolutionary power may be beneficial in further reducing household energy demand.

Sections 5 and 6 address the options for reducing emissions by decarbonising energy supplies, focusing on the opportunities and potential for micro and distributed generation, but also addressing large scale renewable and low carbon generation as the technological choices made at all scales will underpin the achievement of Scotland's emissions reduction targets across all sectors.

Section 7 presents a range of evidence on behaviour change, adaptation, and community empowerment, including a summary list of common themes in the evidence of 'what works.'

Section 8 presents the key conclusions and recommendations that have emerged from the study, and Section 9 provides summary lists of recommendations for 2022-2030 and beyond 2030 referenced to the main body of the report.

The evidence and input to this report was drawn from literature, experts at Glasgow Caledonian University and their networks of associates, and also from information provided by the Scottish Government, however the views expressed herein should be attributed to the authors. A full list of contributors is provided at the end.

1. Introduction

The 'RPP1' Report Low Carbon Scotland: Meeting the Emissions Reduction Targets 2010-2022¹, sets out how Scotland can deliver annual targets for reductions in emissions to 2022, including a 42% reduction in emissions by 2020 compared to 1990. RPP1 sets out policies and proposals for six economic sectors: energy supply; homes and communities; business and the public sector; transport; rural land use; waste.

The 'Homes and Communities' theme under RPP1 sets the following milestones for 2020:

1. Every home to have loft and cavity wall insulation, where this is cost-effective and technically feasible, plus simple measures such as draught-proofing and pipe lagging;
2. Every home heated with gas central heating to have a highly efficient boiler with appropriate controls; and
3. At least 100,000 homes to have adopted some form of individual or community renewable heat technology for space and/or water heating

This report assumes that these milestones will largely have been achieved by 2022, however some discussion is included on areas where evidence suggests there are risks of failure, and also where opportunities exist to exceed the aims and objectives. The report distinguishes between devolved and non-devolved issues and identifies several areas where greater devolutionary powers may be beneficial, but does not attempt to account for the impacts of any further devolution beyond the status quo. The aim being to develop a set of further recommendations for consideration for inclusion in the second Report on Policies and Proposals (RPP2) for beyond 2022, in light of Scottish housing and households are expected to change as a result of the low carbon agenda and other influences on energy consumption.

2. Trends in UK household energy use

Across the UK carbon dioxide emissions from housing have fallen since 1970 but remained fairly stable from 1995 onwards. This is in spite of an increase in the total number of households and changes in the way energy is used, including factors such as increased expectations for thermal comfort and a rapid growth in the proportion of electricity used by appliances and consumer technology. Average household energy use has also fallen in real terms from 22,235 to 18,639 kWh from 1970 to 2009, with the levelling off observed since 1995 due to the overall increase in the number of households, matched by a decrease in average occupancy.

A significant factor in this decrease in emissions has been the shift in electricity generation from coal to gas and, to a much lesser extent, nuclear, leading to a reduction of around a quarter in carbon dioxide emissions per unit of electricity. A similar shift has been observed for the fuel used in homes, with gas use trebling since 1970 and solid fuel use falling to below 2%. The increase in gas use is likely to be due to a mix of factors including greater connectivity to supply networks and consumer preferences, but cost is also a factor as the price of gas has fallen in real terms, whereas electricity, oil and solid fuel prices have risen significantly.

¹ Available at: <http://scotland.gov.uk/Publications/2011/03/21114235/0>

It should be noted that these trends are not unidirectional and whilst there is a clear correlation between household spending on energy and changing fuel prices, there is (as yet) no such cause and effect between falling consumption and the onset of the economic recession. However as changes in household energy demand have been found to lag behind changes in energy prices it is likely that this trend may occur over the next few years.

Other factors that are influencing changes in household energy consumption include the following:

- Improvements in the Building Regulations, leading to a consistent increase in SAP ratings
- Promotion and uptake of common energy efficiency measures
- The changing climate – warmer winters
- An increase in occupants' expectations of thermal comfort, which has largely offset savings from improvements in insulation and the efficiencies of heating systems
- A rapid and sustained rise in energy demand for appliances and consumer technology
- A decline in energy use for water heating and cooking, related to the switch to gas
- An ageing population
- An ageing housing stock and levels of maintenance
- A rapid increase in the number of employees working from home
- Changes in the tenure mix – for which the recent growth in the (less energy efficient) privately-rented sector is a particular problem.

It should be noted that these conclusions have been drawn for the UK as a whole, and the strengths of these influences are likely to vary in the Scottish context, for example due to the lack of mains gas connections in highly rural areas². 91.8% of UK households are connected to the gas grid, but this is only 86.4% in Scotland, with 76.1% of Scottish homes having gas central heating³. However whilst 99% of homes in urban areas of Scotland are on or near (within 0.5km of) the gas grid this figure is only 54% for homes in rural areas⁴.

It is also important to note the impact of the 'rebound effect' where energy efficiency improvements do not translate directly to reduced consumption. Examples of this include homes with improved insulation being heated to higher levels, the savings from the switch to energy efficient lighting being offset by homes having greater numbers of light fittings, and 'environmentally friendly' services and appliances being used for longer periods.

Finally, there are also trade-offs with other energy demands, for example between the transport energy savings from home workers being offset against greater energy demand for domestic heating and appliances⁵.

² Scottish Renewables. Microgeneration in Older Housing. Available at: <http://www.changeworks.org.uk/uploads/David%20Cameron.pdf>

³ Consumer Focus, 2011. Off-gas consumers. Available at: <http://www.consumerfocus.org.uk/files/2011/10/Off-gas-consumers.pdf>

⁴ SHCS 2011. Scottish House Condition Survey: Key Findings 2010. Available at: <http://www.scotland.gov.uk/Publications/2011/11/23172215/0>

⁵ DECC, 2011. Great Britain's Housing Energy Fact File

3. The Scottish housing stock

One of the difficulties in interpreting the UK-level assessment is understanding how the differences between Scottish households and those of the rest of the UK affect any conclusions that may be drawn from it.

The Scottish housing stock currently numbers around 2,344,000 dwellings, and its profile is distinct from that of the rest of the UK. It is comprised of an even mix (20-24%) of detached, semi-detached, terraced, and tenement properties, with a small number of other types of flat. Around one third of the stock was constructed pre-1945, and the iconic pre-1919 Scottish tenements still characterise many urban areas. Since 1981 the Scottish housing stock has grown by around 25%, second only to growth in the south and east of England. In recent years this new build has been dominated by detached properties however the number of modern tenements has grown, whilst the number of new semis has fallen and the number of new terraces dropped significantly after 1982⁶.

Table 1 Mean CO₂ emissions (tonnes / year) in dwellings in Scotland

Source: See Footnote [3]

Age of dwelling	Fraction of national total	Type of dwelling (tonnes/yr)					Emission by Age of dwelling (tonnes/yr)
		Detached	Semi-detached	Terraced	Tenement	Other flats	
Pre-1919	19%	17.5	11.2	9.5	5.2	8.8	9.9
1919 – 1944	14%	15.7	8.1	6.1	4.2	4.4	7.0
1945 – 1964	22%	12.4	6.7	5.3	3.9	4.3	5.7
1965 – 1982	23%	9.2	6.0	5.0	4.2	3.9	5.9
Post-1982	22%	7.5	4.5	4.0	3.3	3.1	5.2
ALL	100%	11.0	7.0	5.6	4.2	4.8	6.6

Such characteristics set the Scottish housing stock apart from that of the rest of the UK, and therefore improving the energy efficiency of Scottish housing will require approaches that are sensitive to these differences and responsive to the barriers and opportunities they pose.

Furthermore, as a result of the economic recession the level of new domestic build in Scotland in 2010 was down by over 34% from the high point in 2007, and whilst fears of a double dip recession remain any recovery is likely to be slow. However reducing emissions from both new and existing Scottish housing remains an important priority for policy and so opportunities must be identified and implemented alongside the economic recovery, and full advantage must be taken of any opportunities that may result from greater devolution.

The challenges ahead are summed up by an Energy Saving Trust report that concluded that the UK would have to "throw everything" at its housing in order to achieve an emissions reduction of just 68% by 2050⁷. Furthermore, whilst historically the emphasis has been on driving energy efficiency by increasing standards for new build, the low turnover rate means that it is likely that the majority of housing around today will still be around in 2050. This necessitates a significant shift in focus towards retrofitting existing buildings and 'soft' measures such as behaviour change.

⁶ Scottish House Condition Survey. Key Findings 2009. DECC, 2011. Great Britain's Housing Energy Fact File

⁷ EST, 2008. Towards a long term strategy for reducing carbon dioxide emissions from our housing stock

However the greatest risk for not achieving Scotland's emissions reduction targets is failing to sufficiently decarbonise the National Grid and it is here that the built environment, geography, and society of Scotland provide a host of valuable opportunities. Not least of these are the significant renewable energy resources that can be harnessed in both urban and rural areas, as well as offshore.

4. Review of current policies and proposals for low carbon built environment

Table 2: Current landscape of policies and proposals for LCBE

	Type		Application		Responsibility	
	Fabric	Grid de-carbonisation	New build	Existing	Devolved	Non-devolved
Policies						
Smart meter			X			X
CERT	X			X		X
CESP	X			X		X
EAP	X			X	X	
HIS / UHIS	X			X	X	
Energy Stds. 2007/2010	X	X	X	X	X	
RHI		X				X
Proposals						
Fuel poverty & insulation	X			X		X
Domestic energy std 2013	X		X	X	X	
Regulations en. efficiency	X			X	X	
ESSAC	X	X		X	X	
Local Housing Strategies	X		X	X	X	
LESA	X			X		X
EPBD	X		X	X		X
Tolerable Std.	X			X	X	
Reduce emission from Social Housing	X			X	X	
Loans to landlords	X			X	X	
HSCCC	X			X	X	
CCF				X	X	
Green Deal	X	X		X		X
ECO	X			X		X

The current landscape of policies and proposals for a low carbon built environment (LCBE) can be grouped into strategies for '*fabric improvement*' and '*grid decarbonisation*.' The former can be further sub-divided into new build and existing stock while both groups could be looked upon as 'devolved' and 'non-devolved' issues.

4.1 Devolved responsibilities

In this sub-section we look at Scotland-specific issues for technically improving the energy performance and quality of Scottish housing. In those cases (especially proposals) where this is not possible, we examine similar schemes elsewhere to learn likely lessons.

4.1.1 Improving the quality and performance of existing buildings

There is an accepted correlation between poor housing and ill health⁸. Dampness, cold and mouldy conditions are linked strongly to health risks for occupant. However, there are mixed messages and contradictory findings from detailed studies into fundamental issues, including the prevalence of asthma. In general there is a lack of a coherent evidence base to support any claims regarding the impact of housing refurbishment on health improvement⁹. Some generalised messages can be derived from considering the possible impact of refurbishment:

- Where refurbishment allows some thermal comfort improvement in under-heated housing this could have a positive health impact, particularly amongst elderly occupants.
- Where refurbishment reduces dampness problems or resultant mould issues, there could be a benefit for occupants in terms of reduced risk of respiratory problems.

Interventions to refurbish a building which improve insulation without compromising internal air quality or ventilation provision should not have a negative health impact and may have a health benefit.

4.1.2 The Energy Assistance Package (EAP), Home Insulation Scheme (HIS), Universal Home Insulation Scheme (UHIS), and Tolerable Standards

The Scottish Government's Energy Assistance Package (EAP) has been described as *"the best UK exemplar in terms of providing both a comprehensive approach ... and to linking the fourth level of assistance to the energy inefficiency of the home"*¹⁰. In its first year the EAP along with the Home Insulation Scheme (HIS) achieved the installation of 11,502 new heating systems and 26,110 measures, at a cost of £65.9 million.

Both schemes use a staged approach leading from offering advice through to installing grant-funded energy efficiency measures in qualifying households. The effectiveness of this approach has been found to be heavily dependent on retaining the engagement of households from stage to stage¹¹, however the appropriateness of installing different measures in different homes and the need to target resources at the most vulnerable members of society means that the number of applicants who drop out of the statistics in the earlier stages is less important than those who drop out later. In this respect a key indicator of the success of the EAP is the 91% of pensioner households referred from Stage 3 to 4. However it should be noted that Stage 4 is referral rather than actual installation, and therefore there remains work to be done to complete a full evaluation of the scheme. Nevertheless, the evaluation does show that the main problems that arose stem from supply not being able to meet demand, particularly in rural areas, which is a

⁸ D Wilkinson, 1999. Poor Housing and Ill Health: A summary of Research Evidence. Scottish Government. Available at: <http://www.scotland.gov.uk/Resource/Doc/156479/0042008.pdf>

⁹ Douglas M, Thomson H, Gaughan M. 2003. Health Impact Assessment of Housing Improvements: A Guide. Public Health Institute of Scotland, Glasgow

¹⁰ Dr Brenda Boardman, Oxford University. Quoted in: Scottish Government, 2010. Home Energy Schemes 2009-10: Energy Assistance Package and Home Insulation Scheme: End Year Report

¹¹ Centre for Sustainable Energy and National Energy Action, 2005. 'Warm Zones Evaluation: Final Report'. Available at: <http://www.warmzones.co.uk/050301%20-%20Warm%20Zones%20Evaluation%20Final%20Report.pdf>

reassuring outcome for a successful pilot project. The evaluation of the HIS is perhaps less positive, but it is clear that the weaknesses have been identified and addressed¹².

A caveat to the effectiveness of these schemes in reducing domestic emissions is that, by being aimed at reducing fuel poverty, they refer many applicants on to cheaper electricity tariffs that invariably source more electricity from fossil fuels. This highlights a key contradiction between driving energy efficiency and reducing fuel poverty, and therefore the need for a multi-pronged approach to addressing them.

A current risk to the EAP and HIS is the accessing of CERT for part of their funding. At present CERT and CESP will be replaced by ECO and any cuts made in England and Wales will not apply in Scotland as the Scottish programmes will continue. However given the clear value of these schemes, the fact that they are factored into the conclusions of RPP1, and the level of demand already being placed on them, it would be prudent to address any future risks to funding well in advance in order to sustain, and potentially expand, the services.

A key opportunity offered by the EAP, HIS and UHIS is the potential to expand the scope of the measures they cover in order to maximise the cost and carbon efficiency of each intervention (see also Sections 4.2.3, 4.2.5 & 4.3.2). A further opportunity for enhancing these and other schemes will be the knowledge to be gained from comparing the success of HIS with that of the Universal Home Insulation Scheme (UHIS) once the first evaluation has been completed¹³.

4.1.3 Problems within the scope of issues addressed by Scottish new build domestic energy standards, 2007 to 2013

The Scottish Building Standards provide requirements and guidance for both the energy performance of new buildings in Section 6 and also for the ventilation required to achieve good air quality in Section 3. If these Standards are adhered to and occupants use the dwelling correctly then health issues should be minimal. However, occupants can still cause problems through unanticipated interventions such as:

- Sealing background trickle ventilators to reduce drafts
- Disabling bathroom / WC mechanical fans to reduce noise
- Undertaking activities which generate excessive moisture loads

In 2010 Section 5 (energy) expanded the role of post construction pressure testing of buildings in acknowledgement of the need to verify building infiltration rates as a factor in both heat loss and ventilation in buildings. This recognised that, as a consequence of higher energy standards, the construction industry may seek to improve the air tightness of new dwellings and as a result reduce unwanted ventilative heat loss. There are risks associated with reducing this unwanted ventilative heat loss in terms of possible air quality issues where occupant action prevents intentional ventilation. These risks are expected to increase in future as a result of rising temperatures, higher rainfall, and higher wind speeds increasing the levels of dampness and

¹² Scottish Government, 2010. Home Energy Schemes 2009-10: Energy Assistance Package and Home Insulation Scheme: End Year Report

¹³ DECC, 2011. Evaluation of the Community Energy Saving Programme. Available at:
<http://www.decc.gov.uk/assets/decc/11/funding-support/3342-evaluation-of-the-community-energy-saving-programm.pdf>

mould growth in both new and existing buildings, along with their associated impacts on human health. Higher summer temperatures will also lead to increasing cooling demand, although some of this demand will be offset by lower heating demands in winter, with likely knock-on benefits for fuel poverty¹⁴. The priority here should be to ensure that as standards are improved for energy efficiency, potential difficulties with the internal environment are understood, and that ventilation provision is correctly specified. As the performance requirements are progressively improved care will be needed to evaluate any potential impacts on the internal environment (see also Section 4.1.6). Further recommendations are given in Section 8.1.

Researchers in Glasgow are currently examining the environmental effects of domestic laundering as part of an EPSRC project. This study has still to publish, however it will report a strong link between biological activity in the air and the amount of passive drying of clothes internally. This suggests that dedicated secure drying spaces would be advantageous in new dwellings for facilitating passive drying, particularly as the air tightness of dwellings is being targeted for improvement.

Another study commissioned by the Scottish Government that is due to report findings relevant to these problems is considering the impact of the environment on children's health in poorer areas of Scotland, including the impacts of dampness on asthma. One finding from this work has been the conflicting advice given to (fuel poor) householders with respect to ventilating their properties to reduce damp whilst having to bear the additional heating costs to maintain some level of thermal comfort¹⁵.

4.1.4 Problems particular to housing in exposed locations

One subset of the Scottish housing stock which shares many commonalities with housing in England and Wales are those properties in exposed locations. The majority of the west coast of Scotland is generally rated as very severely exposed to driving rain¹⁶ and as such requires special protection of the construction detailing to avoid rain penetration problems. Traditionally this has occurred through vernacular details such as protective eaves overhangs, recessed window detailing and the use of render finishes. When refurbishing existing buildings in severely exposed locations care is needed to avoid compromising the weather-tightness of the structure. A particular risk factor in these locations is cavity fill insulation which can allow water to transmit across the cavity and cause internal dampness problems. Much post war housing was built with cavity walls that contained a 50mm or smaller clear cavity, for these walls BRE's guidance indicates that typically:

- In very severely exposed locations cavity fill is not recommended unless the wall is completely protected with an impervious cladding.
- In severely exposed location cavity fill is possible if the wall is completely rendered.

The technical guidance contained in Thermal Insulation: Avoiding Risks on the suitability of cavity fill insulation allows a range of factors to be accounted for including the external wall finish, the

¹⁴ Scottish Building Standards Agency, 2005. Review of Guidance on Energy and Environment. Available at: <http://www.scotland.gov.uk/Resource/Doc/217736/0096692.pdf>

¹⁵ Environmental Determinants of Public Health in Scotland. Final Report to the Scottish Government due end of 2011

¹⁶ Building Research Establishment, 2002. *Thermal Insulation: Avoiding Risks*. BRE Report 262, Watford

local topographic exposure and shelter, the cavity width and the type of insulation being used. It is important that a proper assessment of local risk is made before cavity wall insulation is installed. Localised assessment could mean that the exposure risk of a particular building may be increased or decreased. Failure to account for the local exposure could mean that cavity wall insulation is not prescribed despite localised shelter being sufficient to enable it, and this building instead being labelled as hard to treat.

4.1.5 Problems particular to tenure

Two key barriers to improving the energy performance of the Scottish housing stock are the number of mixed tenure housing blocks and the relative lack of improvement in the energy efficiency of the growing privately-rented sector (9% of privately rented dwellings are categorised as poor for energy efficiency, compared to 3% for owner occupied dwellings and 1% of dwellings in the social sector)¹⁷.

Barriers to improving the energy efficiency are particularly high for privately-rented homes¹⁸. The principal reasons for this being the lack of incentives for landlords to invest in improving the efficiency of their properties, and despite the introduction of Energy Performance Certificates there is no evidence to show that these have resulted in higher-rated properties commanding premium rents¹⁹.

Of the potential options for addressing the problem of energy inefficiency in the privately-rented sector, those that are likely to be most effective are strongly biased towards using regulation to trigger and enforce building maintenance and improvement. Simply relying on the current system of using revised building standards to drive improvements in energy efficiency where new work is carried out in these properties will be insufficient if Scotland's energy efficiency and emissions reduction targets are to be met. Provisions for how further improvements may be informed and achieved through wider assessment and understanding of household energy consumption are contained in section 64 of the 2009 Climate Change (Scotland) Act.

Although there is no 'silver bullet' option that would both deliver significant improvements and be publicly and politically acceptable at present it is likely to be necessary to engineer a change in attitudes to support and enable a more regulatory and enforcement driven approach to tackling the privately rented sector. Examples include, using trigger points to enforce the upgrading of housing to minimum standards whilst being sensitive to the composition of the housing stock and any impacts on supply and demand for housing. In the short to medium term it may be useful to consider appropriate financial incentives to encourage those most open to improving their properties to do so, and soften the blow of increased regulation. Obviously the development of

¹⁷ Consumer Focus Scotland, 2011. Energy efficiency in the private sector housing in Scotland: Regulation and the consumer interest

Scottish Government, 2009. Review of the Private Rented Sector: Volume 1: Key Findings and Policy Implications.

Kemp PA, Rhodes D. 1997. The motivations and attitudes to lettings of private landlords in Scotland. *Journal of Property Research*, **14**, 117-132

Communities Scotland, 2005. Housing and Disrepair in Scotland: Analysis of the 2002 Scottish House Condition Survey

¹⁸ Consumer Focus Scotland, 2011. Energy efficiency in the private sector housing in Scotland: Regulation and the consumer interest

¹⁹ Britnell J, Dixon T. 2011. Retrofitting in the private residential and commercial property sectors – survey findings. Retrofit 2050 Working Paper. Oxford Institute for Sustainable Development (OISD), Oxford Brookes University

such a strategy must also consider the current and future capacity of partners and stakeholders to deliver it²⁰. The Loans to Landlords scheme (LtL) and the Landlords' Energy Saving Allowance (LESA) are two possible vehicles for this, however any decisions to be made over adopting and adapting one or other will need to consider the opportunities and barriers presented by their different statuses as regards devolved powers. As with all decisions that consider devolutionary issues there are likely to be trade-offs between leveraging funding at a UK level and enabling greater sensitivity to the needs of Scottish housing and households.

As more regulatory-driven approaches to reducing emissions from the housing stock are likely to be less publicly and politically acceptable the current performance of these properties makes a stronger case for regulation than for other tenures. However they should also be considered with respect to the wider benefits, such as generating new employment, as well as their cost-effectiveness with respect to voluntary approaches. A world-leading example of such a regulatory approach, which has been applied cost-effectively across all tenures, is the Residential Energy Conservation Ordinance²¹ pioneered by the City of Berkeley, California.

For mixed tenure blocks the 2004 Tenements (Scotland) Act may present some opportunities for reducing emissions from housing that could be considered for prioritisation. The Act was a step forward in addressing problems with the process of gaining consent and payment from residents for maintenance work on tenement blocks. In the future it may be advisable to explore the potential to extend the regulatory scope of the Act, and amend it to include energy efficiency improvements (beyond insulation) and building-integrated renewables, particularly with respect to any measures that could simplify the process of gaining consent in mixed tenure blocks²².

Whilst any such amendments to the Act would need to be sensitive to potential human rights issues, for example whether or to what extent a low energy consuming household sharing a block with more energy profligate households should contribute to the costs of an intervention, these are not necessarily insurmountable. For example the more accurate data that will be obtained from the roll out of smart meters (see Section 7.4) could be used in conjunction with basic household information to apportion costs more fairly, in line with the 'polluter pays' principle and adjusted by ability to pay.

More widely, another potential lever here may be through providing residents with limited information on the energy consumption of their neighbours in order to introduce an element of competition²³. However despite evidence for the potential of such approaches, and the good intentions behind them, public opinion over the collection and sharing (and loss) of personal data strongly suggests that any such initiatives could be highly unpopular and their potential limited to voluntary action (see Table 8 for international experience on these matters).

²⁰ Scott J, Baker K.J., Reid S. 2010. Improving Energy Efficiency in the Housing Sector in Scotland: Exploring the Role of Regulation. Report to Consumer Focus Scotland as input to their 2011 report 'Energy efficiency in private sector housing in Scotland: Regulation and the consumer interest'. Available on request.

²¹ Office of Energy and Sustainable Development, City of Berkeley, n.d. 'Residential Energy Conservation Ordinance'. Available at: <http://www.ci.berkeley.ca.us/ContentDisplay.aspx?id=16030>

²² Scottish Government, 2008. Evidence on Hard to Treat Properties.

²³ Darby S. 2005. Social learning and public policy: Lessons from an energy-conscious village. *Energy Policy*, 34, pp. 2929–2940

If, as it appears, competition has some potential to reduce energy demand, then a fundamental question here is how much an average household would accept that their neighbours (or anyone else) could know about their energy consumption - and conversely how much they would need to know about that of others for competition to work. A possible, if somewhat brave, attempt to test this is the very public 'traffic light' system planned for PortZED, near Brighton²⁴, whereby the energy consumption of the blocks will be indicated on lights mounted on the building-integrated wind turbines. The success of the development in general and residents' reaction to such public 'display' of energy consumption in particular remains to be seen. The demographics of those choosing to live there will need to be taken into account when interpreting the outcomes of the project. Nevertheless the lessons learned from it will be invaluable in both designing the low energy developments of the future and in informing how behaviour change can be influenced by the built environment.

4.1.6 Scottish new build domestic energy standards, 2013 – 2022

It is important to remember that most of the energy efficient and sustainable (or otherwise) housing that will exist in 2030, and even 2050, is already in existence today. The present rate of new build housing has fallen significantly in the last 3 years (from 25,736 house completions in 2007 to 16,893 in 2010 – a drop of over 34%. The drop in new dwelling starts in the first 3 quarters of 2011 is nearly 40% over that of 2010²⁵) and there are no indications that this will change significantly at least until the economic recovery begins. However this pause in housing development may be beneficial in the long term as the costs and cost effectiveness of new technologies and approaches to improving energy efficiency performance should continue to improve regardless of the recession, or possibly even because of it. Whilst there is a legitimate concern that low rates of new build will not drive down unit costs as rapidly as in a more healthy market, it should be possible to offset this if the measures adopted for existing build can generate sufficient new demand. Similarly, revisions to the Building Regulations will also improve the performance of new build, and aside from the more technical discussion of what minimum measures should be added or increased, the only question here is what the desired rate of change should be.

The findings of the 2007 Sullivan Report, the conclusions of the recent consultation on revisions to the Scottish Building Regulations, and the recommendation in the Sullivan report for Scottish new build to be net zero carbon by 2016/17 set the main context and aims for the immediate future of Scottish new build. The main impact of the recession on this future has been questioning whether housing developers will still be willing and / or able to meet these aims without significantly impacting on build rates. As the latest revisions to the Scottish Building Regulations came into force around the beginning of the recession (Oct 2010) it is an intrinsically difficult task to disentangle their influences on the fall in the rate of new build - for example a more environmentally-minded developer may blame the recession whilst a less environmentally-minded one may blame regulation, but the respective realities are likely to be more complex. Further research into these issues will be needed in order to respond to future recessions,

²⁴ PortZED website: http://www.zedfactory.com/projects_in_development_portzed.html

²⁵ Scottish Govt., Communities Analytical Services (Housing Statistics), 2011. New House Building in Scotland. Data available at <http://www.scotland.gov.uk/Topics/Statistics/Browse/Housing-Regeneration/HSfs/NewBuild>, last accessed 07.12.2011

however this would be unlikely to be able to deliver conclusive results within a short enough timeframe to be immediately useful.

As regards the over-riding question of the rate of change, if it is assumed that the rate of new build housing, and its rate of recovery, will rebound similarly to the wider economic recovery, and accounting for the wider benefits of being able to capture that new build, there is no clear evidence to recommend a change in the trajectory for standards.

4.2 Non devolved responsibilities

This section examines the evidence for the UK and the wider EU related policies and proposals both for fabric improvement and grid decarbonisation.

4.2.1 Energy Performance of Buildings Directive and Energy Performance Certification

The most well-known output of the EU's Energy Performance of Buildings Directive (EPBD) is the requirement for new and newly tenanted homes to be assessed for and display Energy Performance Certificates (EPCs). However there is no evidence that EPCs as they currently stand have yet to be instrumental in driving up demand for energy efficient housing in Scotland or the UK, and the (limited) evidence from other areas suggests its more immediate outcome will be the 'price chipping' of poorer quality stock²⁶. In the longer term this may change due to increased public awareness and higher energy prices, however at the moment there is no evidence to suggest the beginning of a trend in this direction (see also Section 7.1).

4.2.2 New buildings to 2022

There is a small but growing body of evidence on the actual energy/carbon and initial cost performance of Code for Sustainable Homes (CSH) buildings in England which, while not directly applicable in Scotland, hold important lessons for sustainability enhancement efforts in Section 7 of the Scottish Building Standards.

A comprehensive performance evidence (albeit a short term – less than 3 years) for CSH 3 homes comes from a small development of fourteen homes constructed in Lingwood, Norfolk (Development comprises of seven 3-bedroom homes and seven 2-bedroom homes, constructed using a timber frame system that achieved a Code for Sustainable Homes Level 3). The evidence given below compared a house built to 2006 Standards ('CONTROL' – See Table 3 for construction details) with CSH3 homes that use one of the following approaches to energy/carbon reduction over and above the 'CONTROL' home: Ground Source Heat Pump with an underfloor heating loop in the ground floor plus radiators upstairs ('GSHP'), grid connected solar PV and hot water system

²⁶ Dixon, T., Keeping, M., & Roberts, C., 2008. Facing the future: energy performance certificates and commercial property. *Journal of Property Investment & Finance*, Vol. 26 No. 1, 2008, pp. 96-100.

Watts, C., Jentsch, M.F., & James, P.A.B., 2011. Implications of Energy Performance Certificates for the UK domestic building stock – Feedback from a Southampton homeowner survey. CIBSE Technical Symposium, De Montfort University, Leicester, UK – 6th and 7th September 2011.

(‘SOLAR’) and passive solar sunspace with Mechanical Ventilation with Heat Recovery (‘MVHR’) - see Figure 1.

Table 3: Thermal and energy parameters of the ‘CONTROL’ home

Source: See Footnote [17] below

Parameter	Value
U Value – Wall	0.18 W /m ² • K
U Value – Floor	0.16 W /m ² • K
U Value – Roof	0.14 W /m ² • K
U Value – Windows	1.80 W /m ² • K
U Value – Doors	2.40 W /m ² • K
Air permeability	7 m ³ /m ² • h @ 50 Pa
Heat loss	1.33 W /m ² • K
Carbon emission	22.3 kg/m ² •yr
Space + water heat demand	50.0 kWh/m ² •yr

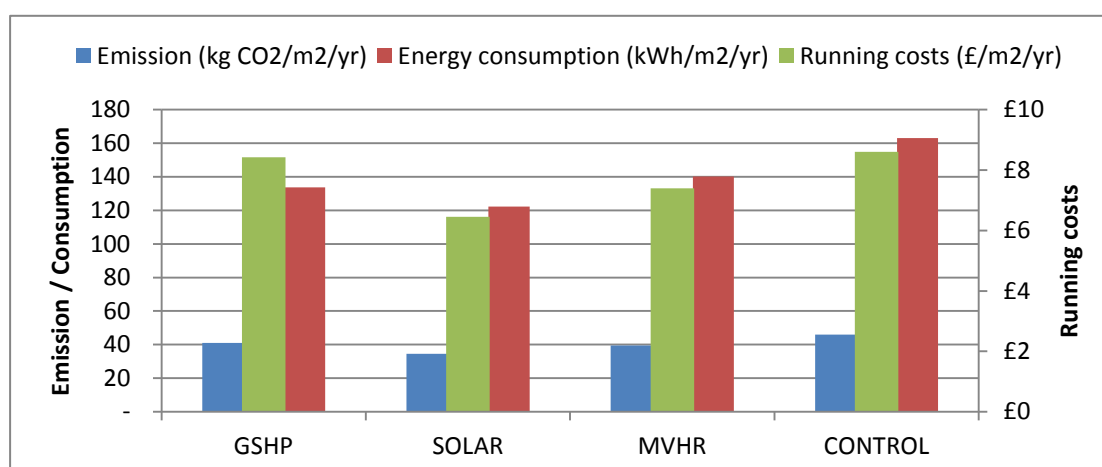


Figure 1: Energy and carbon performance of standard (‘CONTROL’); Solar PV (‘SOLAR’); Ground Source Heat Pump (‘GSHP’) and ‘Passivhaus’ (MVHR)²⁷

All three improvements to the CONTROL used less energy than the CONTROL house: SOLAR 25%; GSHP 18%; MVHR 14%. All three ‘low carbon’ alternatives to CONTROL also had lower emissions: GSHP 11%; SOLAR 25%; MVHR 14% (Figure 1). The GSHP houses had relatively high CO₂ emissions due to the higher carbon intensity of grid electricity compared to mains gas.

Evidence for construction cost for CSH buildings was recently published by the Dept for Communities and Local Govt. (see Figure 2).

²⁷ Monahan J, Powell JC. 2011. A comparison of the energy and carbon implications of new systems of energy provision in new build housing in the UK, *Energy Policy*, **39**, pp. 290–298

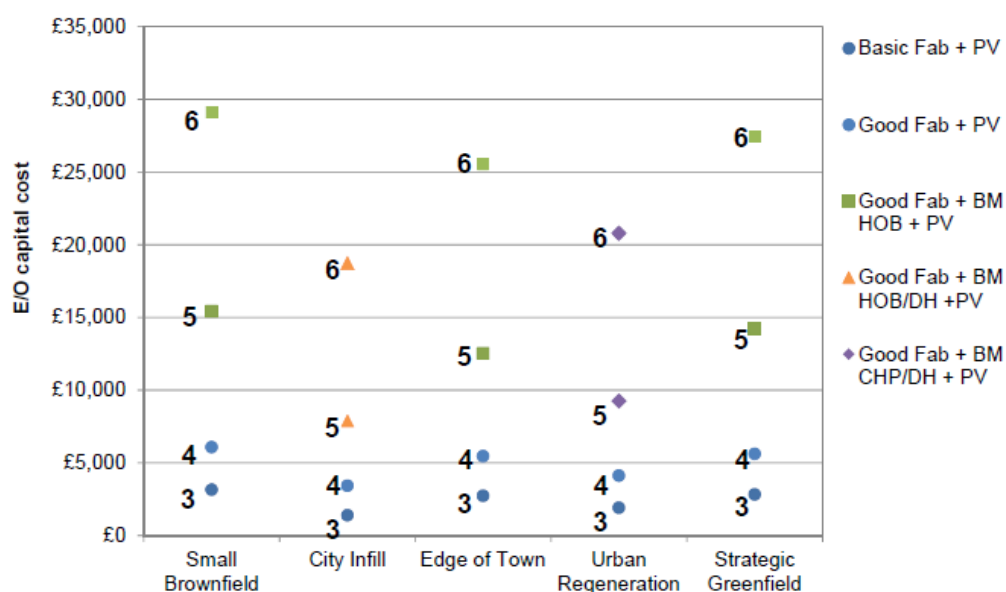


Figure 2: Extra-over (E/O) costs of CSH 3 to 6 homes in different locations in England²⁸

A significant fraction of the costs of building to Code standards are incurred under the Energy and CO₂ category of the Code. Within the Energy and CO₂ category, a large part of the spending is related to the energy solutions adopted in order to meet the mandatory Dwelling Emissions Rate (dwelling emission rate) standards set out under issue Ene 1 of the Code. There appears to be a relatively homogeneous approach to date across the industry to achieve the Code level 3 dwelling emission rate standard. Typically meeting Code 3 requirements has involved improvement of the building fabric in combination with a solar thermal system or small PV array. The Code level dwelling emission rate standard can be achieved through fabric improvement alone at a similar extra-over cost to strategies involving low carbon generation and several home builders cited a preference to avoid installing generator technologies on grounds of simplicity.

To achieve the Code Level 4 dwelling emission rate standard, the common approach seems to be a further improvement in fabric standard, combined with a PV array. The consultation revealed too little experience of building to Code level 5 or 6 for any common approaches to be identified. At Code level 5 and 6, biomass-based community energy strategies tend to be more cost-effective, particularly in the larger-scale, higher density development scenarios. The key lesson for Scotland from all of the CSH efforts is the vital importance of decarbonising the grid – both in terms of electricity as well as heat. These are further discussed in Sections 6 and 8.2 respectively

4.2.3 Carbon Emissions Reduction Target (CERT)

The UK's Carbon Emissions Reduction Target (CERT) is being retired at the end of 2012 and will be replaced by the Energy Company Obligation (ECO). Whilst under current proposals this will not impact on the funding available to those Scottish schemes that source some of their funding from CERT (and CESP), if they are to continue to contribute to reducing emissions as set out in RPP1 it

²⁸ DCLG, 2011. Cost of building to the Code for Sustainable Homes: updated cost review, Dept for Communities and Local Govt. <http://www.communities.gov.uk/documents/planningandbuilding/pdf/1972728.pdf>

will be necessary to insure that the total funding available to them over the long term is sufficient, or exceeds, the levels on which the figures given in RPP1 are based.

CERT has also been criticised for a number of reasons, but from the perspective of reducing emissions from housing the most notable of these is an apparent bias towards delivering energy efficiency improvements over micro and small scale renewables²⁹. This criticism reflects the evidence that interventions to install packages of measures (including renewables) are more cost and carbon effective, and a concern that CERT could have done more to support the uptake of micro-generation by poorer households that could benefit more from the savings.

Whilst further evaluative research into CERT and other schemes should be beneficial in improving them, the conclusions drawn from this and other evidence presented in this report are sufficient to broadly support the recommendations made in RPP1 sections 4.56 to 4.58.

4.2.4 Feed in Tariff

In Scotland the impact of the Feed in Tariff scheme has been 11.2 MWe of capacity either transferred from the Renewables Obligation (RO) or installed between the announcement of the scheme and its commencement (July 2009 – April 2010), and 10.5 MWe installed between April 2010 and March 2011. However this 100% growth must be set against the 360% growth for the whole of the UK over the same period. Scotland's progress also differs from the rest of the UK in that growth has been strongest for wind and hydro projects over 500kWe, whereas in the rest of the UK, but particularly in England, the main growth has been in retrofitting solar PVs to homes.

The breakdown of the impact of FiTs by Local Authority also provides important evidence on their impact and value. Only six Local Authorities achieved additional capacities of over 1MWe, these were: Aberdeenshire (predominantly wind); followed by Perth and Kinross (predominantly hydro); Argyll and Bute (approx. 2/3 wind to 1/3 hydro); the Orkney Isles (almost all wind); Dumfries and Galloway (predominantly wind); and the Highlands (approx. 2/3 hydro and an equal split of wind and solar PV). It is notable that these Local Authorities, and most of those higher up the rankings, are all in rural areas. However an exception to this is Stirling, which gained significant commercial investment for hydro, and the value of the contribution from commercial sources is evident in the achievements of all of the top six. In addition, the value of community installations is clearly evident for the Orkney Isles and Argyll and Bute.

Despite the significant disparities in increasing capacity, which are also highly dependent on the size of the Local Authority and the availability of renewable resources, all have gained in capacity to some extent, although this is near zero in some cases and largely solar PV. However it should be noted that even for solar PV new installed capacity has been higher in rural areas, with only Stirling and the City of Edinburgh in the top ten (9th and 10th respectively)³⁰.

A clear conclusion from these results is that in Scotland households in rural areas have been the quickest to embrace the benefits of FiTs, largely as it makes economic sense to switch away from expensive fossil fuel sources, and therefore more needs to be done to increase take up in urban

²⁹ Williams J. 2010. The deployment of decentralised energy systems as part of the housing growth programme in the UK. *Energy Policy*, **38**, pp.7604–7613

³⁰ AEA Technology. 2011. The AEA Scottish Microgeneration Index. Available at:
<http://www.aeat.com/cms/assets/Documents/The-AEA-Scottish-Microgeneration-Index.pdf>

areas. This is not a criticism of the scheme as unlocking the renewable potential of these areas will be critical in meeting Scotland's renewables and emissions targets however it serves to highlight the barriers that remain for the greater uptake of renewables in urban areas. Foremost amongst these being tenure and planning/conservation legislation.

However since the report from which the above evidence is drawn was published the Government in Westminster has already made significant cuts to the incentives for solar photovoltaics under the FiT scheme, and unless revoked as the result of legal action (currently in process) these are certain to reduce its impact in both Scotland and the rest of the UK. As the revision of FiTs for other technologies is currently subject to further consultation, given the growth in wind and hydro in Scotland it would be pertinent to assess the potential impacts on these technologies. Furthermore, given the clear benefits of commercial and community installations to building Scotland's micro-generation capacity, it would also be pertinent to assess the impacts on these.

Most concerning of all, in light of the apparent rationale behind these cuts, is that (in the view of the authors) the future of FiTs appears highly uncertain. This is because of the evidence that those parts of the world that have made the most significant progress in micro and small scale renewables, for example Germany and California, have invariably been those whose governments have sent long term and consistent signals to investors³¹.

Despite the disparities in progress FiTs have clearly boosted micro-generation capacity in Scotland, however it is also inevitable that the impacts of any cuts to FiTs will affect future progress in expanding capacity. Whilst the currently planned cuts to solar appear likely to have less of an immediate impact in Scotland due to the higher capacity of wind and hydro projects, in the longer term there remains the problem of increasing micro-generation capacity in areas where other technologies are more appropriate. Therefore in the immediate term the priority for Scotland should be to continue to work within the limits of the FiT framework to ensure it receives its fair share of the scheme, and in the longer term press for revisions that are more sensitive to the (likely different) priorities for expanding micro-generation in Scotland (see Section 5).

Another important factor to consider, especially in more densely populated urban areas, are the cost savings that can be made from installing micro-generation technologies at the same time as energy efficiency interventions such as insulation top ups and boiler replacements. This is particularly significant for groups of tenements and flats, where the need for scaffolding can add significantly to both the costs and time needed for interventions.

In the long term what is needed here are clear and consistent signs to potential investors in micro-generation. The removal of key planning barriers to wind turbines and air source heat pumps in February 2012 should contribute to increasing their uptake, and monitoring the impacts of these measures should be invaluable for informing any future changes to planning policy. Heat mapping projects (see Section 8.2) should be effective in identifying priority areas and encouraging investment through demonstrating potential, and the forthcoming Micro-generation Strategy is expected to send a clear and positive message to the sector. We are also aware of forthcoming planning advice on micro-generation and renewable heat but unaware of the likely contents. In the future it may be advisable to work with other bodies to address the remaining regulatory

³¹ Scott J, Baker KJ, Reid S. 2010. 'Improving Energy Efficiency in the Housing Sector in Scotland: Exploring the Role of Regulation. Report to Consumer Focus Scotland as input to their 2011 report 'Energy efficiency in private sector housing in Scotland: Regulation and the consumer interest'. Available on request

barriers to micro-generation, for example working with Historic Scotland on revising conservation legislation, to identify instances where further relaxation would be acceptable.

4.2.5 Community Energy Saving Programme (CESP)

The primary source of evidence on the impact of the CESP is the 2011 evaluation report produced for DECC by CAG Consultants, Ipsos Mori and the Buildings Research Establishment (BRE)³². Two difficulties in drawing recommendations and conclusions for Scotland are the lack of data on actual installations (expected in an evaluation to be published in 2012) and a lack of disaggregated data. However this first evaluation has found that take up rates were disproportionately low in London and Scotland, and although the income levels of households was not surveyed as part of the evaluation the evidence presented and experience from similar initiatives suggests it has been less successful in targeting the fuel poor than those less in need. Although the evaluation does not provide a detailed breakdown of the figures, in light of the large number of eligible areas in Scotland it would appear that take up has been relatively low.

Perhaps the most important criticism of the scheme to date has been its complexity for both delivery partners and potential recipients although the evaluation notes that this has been more successful in Wales, where the Welsh Assembly Government has been pro-active in raising awareness amongst Local Authorities and Housing Associations.

Another limitation common to similar initiatives has been the focus on insulation, although this has been found to result in higher levels of thermal comfort even where the impact on improving energy efficiency has been minimal. As discussed in Section 4.3.2, there are significant cost and carbon efficiency gains to be made from more holistic 'whole house' packages of measures, and decisions over the future role of the CESP in Scotland will need to consider the appropriateness or otherwise of this more limited approach in light of the differences in priorities and housing between Scotland and the rest of the UK.

A notable critique of the CESP is the conclusion that the energy supply companies, as both funder and contractor, has led to strained relationships between partners in CESP projects, and it would be useful to understand if and why similar problems exist for CERT. However given the evidence for the importance of identity and culture in community-based initiatives it may be that this finding is more particular to CESP, but with implications for other community programmes. Tenure has also been identified as a barrier to success however this may be better overcome through parallel strategies aimed more specifically at this problem (see Section 4.1.5).

Finally, as for CERT, CESP will be replaced by ECO however the extent of the cuts being made by Westminster requires a note of caution on its future ability to continue to contribute to emissions reductions as set out in RPP1.

4.2.6 The Green Deal and the Energy Company Obligation (ECO)

At the time of writing the Green Deal and the Energy Company Obligation (ECO) are still at consultation stage, therefore this report does not consider their impact as part of its

³² DECC, 2011. Evaluation of the Community Energy Saving Programme. Available at:
<http://www.decc.gov.uk/assets/decc/11/funding-support/3342-evaluation-of-the-community-energy-saving-programm.pdf>

recommendations beyond any assumptions or assertions made in RPP1 and the Environmental Impact Assessment produced alongside the consultation document. However the following comments are made by the authors in response to the issues raised in the (extensive) consultation document³³, based on the issues discussed in this report:

- The proposals recognise both the importance of changing both the built environment and behaviour in reducing emissions, and includes many examples that new evidence is being taken on board.
- The modelling tool to be used is the reduced data Standard Assessment Procedure (rdSAP), however the appropriateness of this tool, particularly in Scotland, is questionable.
- The proposal that under ECO improvements to hard to treat properties will only be funded if the package includes solid wall insulation needs consideration in light of the composition of the Scottish housing stock (Chapter 5).
- The proposal to transfer payment obligations to new owners / tenants follows good practice (e.g. in California) however the (valid) exclusion of small energy generators from ECO (invariably those that source more from renewables) will prevent their customers moving in to these homes from maintaining their contracts.
- Following from the above, new tenants will bear the cost of improvements through their energy bills (p 148) however there may be an equity issue here for those moving into previously sub-standard accommodation. In such cases it may be fairer, if more complex, for the tenant to pay only the costs of improvement beyond minimum housing standards.
- More detail is needed on the Occupancy Assessment and example recommendations, along with further details of the new qualification, to give informed comment (see Chapter 1).
- Importantly, the proposals recognise the benefits of installing packages of measures (p 127).
- For households not connected to the gas grid there will be *"no additional incentive"* for heat pumps or low carbon heat over more traditional approaches (p 74). This appears a cause for concern given the higher proportion of non gas grid connected properties in Scotland.
- The proposals *"do not intend to take account of "active comfort taking" in the savings estimates as the assessment is based on the physical performance of the building"*. This would appear to risk significantly over-estimating energy savings (p 82), and further concerns are raised by the following: *"We do not propose to guarantee that the charge will be fully offset by the savings. This would be extremely difficult to either implement or enforce. However, there is nothing to stop organisations going further and guaranteeing that their measures will save customers money"* (p 106).

As these proposals are still under consultation the comments made here and the implications for RPP2 should be revisited following the final publication of the details of these schemes.

Final note: Following the drafting of this Final Report the author Chris Goodall published a critique of the Green Deal and ECO on his Carbon Commentary blog³⁴, which was then picked up on by

³³ DECC, 2011. *The Green Deal and Energy Company Obligation – Consultation Document*. Available: <http://www.decc.gov.uk/assets/decc/11/consultation/green-deal/3607-green-deal-energy-company-ob-cons.pdf>

³⁴ Goodall, C., 2012. The Energy Company Obligation: a pittance that will worsen the finances of the most poor. Carbon Commentary, 3rd January 2012. Available at: <http://www.carboncommentary.com/2012/01/03/2230>

George Monbiot in the Guardian³⁵. Whilst some of the criticisms made in these articles may not be valid, or as valid, in Scotland they are a cause for concern, particularly in light of the final two points above. Further evaluation of the likely impacts of these schemes will be included in new work commissioned from GCU, however the authors wish to stress two key points made by Goodall and Monbiot: that the overall levels of financial support for energy efficiency, renewables and tackling fuel poverty should not be allowed to fall following the retirement of CERT; and that any new schemes should not ultimately lead to higher bills for the poor.

4.3 Common concerns

4.3.1 Building modelling and post occupancy evaluation

As stated previously, the theoretical energy saving associated with energy efficient refurbishment is usually not fully achieved. After insulation measures have been implemented it has been observed that some of the potential saving is “taken back” by the consumer, in what has been labelled as the Rebound effect³⁶. One of the authors of the present report carried out a meta study in 2006 for the Energy Savings Trust that focussed on energy consumption before and after loft insulation and cavity wall insulation measures had been installed³⁷. This study identified that 15% of the potential saving was taken back by the consumer as improved thermal comfort, i.e. people took the opportunity of improved thermal performance to achieve better internal conditions after refurbishment. In addition, the study identified that typically a further 35% of the potential saving was not realised and this was attributed to a combination of:

- Actual insulation performance once installed being less than in an ideal application. This could in part be attributed to workmanship issues, but also unrealistic assumptions about the building stock and the accessibility of particular cases for good installation of cavity insulation completely throughout the building.
- Occupant controlled ventilation behaviour. There is anecdotal evidence to suggest that some occupants post refurbishment have a tendency to control internal comfort when the house heats more quickly than previously by opening windows and dumping excess heat rather than changing their thermostat settings. This behaviour might evolve with time post refurbishment.
- Limitations in the theoretical models and assessment approaches adopted by the different studies.

In total, the EST study identified that the average actual energy saving after cavity wall insulation and loft insulation is 50% less than could theoretically be achieved. The study was unable to identify any significant influences on this in terms of occupancy or tenure due to the restricted

³⁵ Monbiot, G., 2012. The green deal is a useless, middle-class subsidy. The Guardian, 13th January 2012. Available at: <http://www.guardian.co.uk/environment/georgemonbiot/2012/jan/13/green-deal>

³⁶ Greening LA, Greene DL, Difiglio C. 2000. Energy efficiency and consumption — the rebound effect — a survey. *Energy Policy*, **28**, pp. 389-401

³⁷ Sanders C, Phillipson M. 2006. Review of Differences between Measured and Theoretical Energy Savings for Insulation Measures. Published by DEFRA, available at: http://www.decc.gov.uk/assets/decc/what%20we%20do/supporting%20consumers/saving_energy/analysis/insulation_measures-review.pdf

samples, but it may be reasonable to expect that properties in acute fuel poverty could see greater “take back” in terms of thermal comfort improvement following a refurbishment.

On an individual dwelling basis the energy models used to predict consumption can be wildly inaccurate as they assume a standard pattern of occupant behaviour, and this is often not replicated in practice. Only when the models are scaled up to a reasonable number of properties should the models be expected to reflect actual consumption. Tenure, household size and occupant demographics are also important factors that influence the accuracy of models and as these change we may expect a divergence between predictions and measurements. The effectiveness of refurbishment requires assumptions to be made about the building stock and this is a particular area where there is a degree of uncertainty. Finally the occupant response to refurbishment needs to be properly understood to take account of the rebound effect described above and the particular response that could be expected from households in fuel poverty.

The case of DEMScot model, based on the BREDEM methodology using an ensemble of house type to make representative predictions of the carbon emissions from the Scottish Housing Stock under various refurbishment strategies, needs special mention. Work by Cambridge Architectural Research estimate that the initial DEMScot model predictions for 2020 are accurate to 15%, but are only accurate to 50% for 2050³⁸. However, the initial DEMScot model did not make any allowance for either the Rebound Effect or for Fuel Poverty, both of which could lead to an additional systematic source of uncertainty which could overestimate the carbon emissions that could be realised from refurbishment of the housing stock.

A revised version of the DEMScot model was produced in 2010 which assumes that a rebound effect of 20% occurs for all housing refurbishment measures and all user groups³⁹. This assumption contrasts with the 50% identified by the EST study previously discussed and has been chosen to represent an average that slightly overestimates the rebound in mainstream housing, and underestimate the rebound in fuel poverty housing. Thus the rebound figure of 20% accounts for the different rebound effect in fuel poverty housing with a general approximation. The accuracy of predictions of emissions from the Scottish Housing stock as refurbishment measures are introduced will be sensitive to the value of the rebound effect assumed, and so any inaccuracy in this will lead to an additional systematic error in the results from DEMScot. The figure of 15% uncertainty for DEMScot predictions for housing stock in 2020 is likely to be an underestimate. Future development of DEMScot should continue as evidence on the rebound effect emerges and be informed by future research findings. Use of DEMScot for savings predictions should track the version and assumptions utilised in the calculation and an awareness of this is needed for future scenario modelling.

4.3.2 Improving the cost and carbon effectiveness of interventions

There is a growing body of evidence that installing packages of measures on a home, and treating groups of homes at the same time, significantly improves the overall cost effectiveness of an intervention; and conversely addressing only the low hanging fruit (e.g. insulation) drives up the relative cost of lower priority measures such as renewables. This is also reflected in European

³⁸ Scottish Government, 2009, Modelling Greenhouse Gas Emissions from Scottish Housing: Final Report, p47.
<http://www.scotland.gov.uk/Publications/2009/10/08143041/0>

³⁹ Scottish Government, 2010, DEMScot 2: Scotland's Housing Carbon Model The extensions.
<http://www.scotland.gov.uk/Resource/Doc/1035/0103828.pdf>

Union priorities by the emphasis on funding area level demonstrations of interventions, for example through the FP7 funding stream. For tenements in particular this problem is compounded by the cost of scaffolding, and therefore targeting tenements presents an important opportunity for demonstrating the additional cost and emissions savings from expanding the scope of measures included in energy efficiency schemes. Furthermore, the installation rates that could be achieved using existing mechanisms such as the EAP (and the data on its applicants) could provide a boost to both the status of renewable energy and the wider economy.

Table 4: Draft results of analyses of different interventions on three common housing types

Case study: Pre-1919, Solid wall, Flat	Baseline	Upgrade loft insulation	Internal wall insulation	Replacement boiler	Install warm air GSHP	100% Low Energy Lights	Install solar PV on roof	Combined measures
CO ₂ emissions (kg / year)	3,759	-	3,289	3,226	-	3,726	-	2,826
CO ₂ savings (kg/yr)	-	-	470	533	-	33	-	933
Installation cost	-	-	£4,000	£2,500	-	£20	-	£6,620
Cost per tonne of CO ₂ saved	-	-	£103	-£20	-	£333	-	£50
Payback period (years)	-	-	47	27	-	1	-	38
Case study: 1964-1982, Cavity wall, House	Baseline	Upgrade loft insulation	Internal wall insulation	Replacement boiler	Install warm air GSHP	100% Low Energy Lights	Install solar PV on roof	Combined measures
CO ₂ emissions kg/yr	5,242	5,179	-	4,194	-	-	4,758	3,665
CO ₂ savings (kg/yr)	-	63	-	1,048	-	-	484	1,577
Installation cost	-	£500	-	£2,500	-	-	£8,000	£11,000
Cost per tonne of CO ₂ saved	-	-£0.01	-	-£0.19	-	-	£0.37	-£0.01
Payback period (years)	-	29	-	9	-	-	89	28
Case study: Post 1982, Timber frame, House	Baseline	Upgrade loft insulation	Internal wall insulation	Replacement boiler	Install warm air GSHP	100% Low Energy Lights	Install solar PV on roof	Combined measures
CO ₂ emissions kg/yr	6,534	5,908	-	-	3,686	6,551	5,868	2,776
CO ₂ savings (kg/yr)	-	626	-	-	2,848	17	666	3,758
Installation cost	-	£500	-	-	£10,000	£20	£8,000	£18,620
Cost per tonne of CO ₂ saved	-	-£133.00	-	-	£10	£353	£213	£34
Payback period (years)	-	5	-	-	33	2	64	38

Table 4 and Figure 3, which are based on the draft results of three case studies provided by the Scottish Government, are included to help illustrate this point.

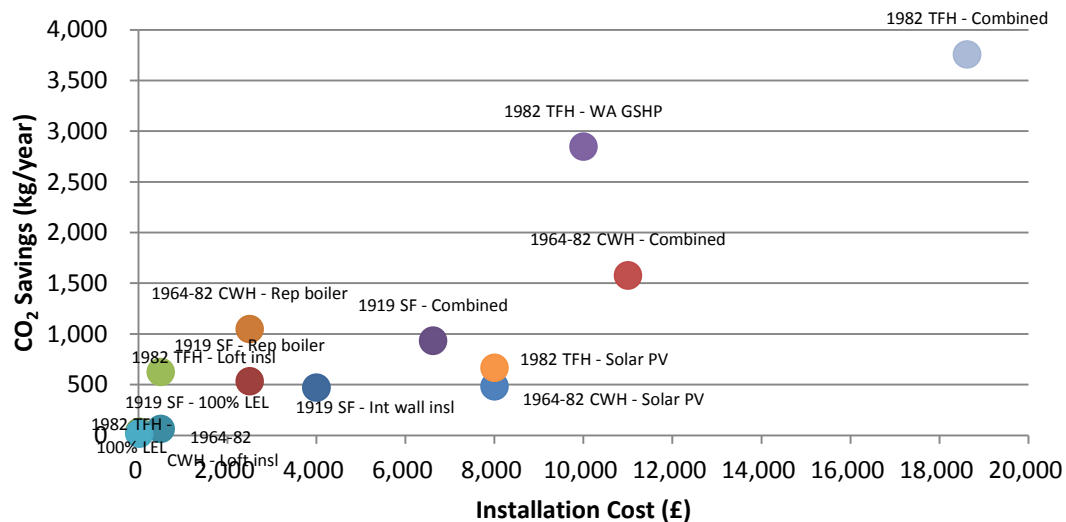


Figure 3: CO₂ Savings versus Installation costs for selected interventions on three common housing types

Note: SF – Solid Wall Flat; CWH – Cavity Wall House; TFH – Timber Frame House

Although these are draft results at this stage they clearly show the added value to be gained in terms of emissions reduction from the additional investment needed to widen the scope of household interventions. One notable result is the CO₂ savings for adding a warm air GSHP alone to the timber frame house are a strong indicator of the benefits of prioritising this measure for suitable dwellings.

Another is the cost effectiveness of the combined intervention on the pre-1919 solid wall flat, however this was the only case study not to include a micro-generation option, and so it would be informative to extend this assessment to the (shared) costs and benefits for a block equipped with solar thermal or PV. Similarly, it would be informative to add solar thermal to the analyses for the other two dwelling types, although more work is needed to reduce the uncertainties over emissions savings that can arise from mismatches in supply and demand for heating and hot water⁴⁰.

Finally, one indicator of the increasing urgency to widen the scope of those intervention measures currently being incentivised is the inclusion of low energy lights in the analyses. The EU's phase out of traditional tungsten bulbs, and the planned extension of the phase out to other less efficient lighting by 2016, will soon mean low energy lighting will cease to be a factor for modelling energy consumption. This will not mean that efforts to reduce energy consumption by lighting, but that efforts to minimise it will increasingly turn to maximising the carbon effectiveness of natural and electrical lighting available in dwellings and other buildings, as well as further research and development of newer lower carbon technologies. However from the perspectives of reducing emissions from the existing housing stock, and from efforts to make further significant reductions from new build, lighting technology is now a low hanging fruit that has been largely grasped.

⁴⁰ Personal communications with Lister Housing Association, Edinburgh, and Secon Solar, Newcastle, as part of work conducted prior to this study

5. Micro and distributed generation in Scotland

The support available for micro and distributed generation in Scotland is set out in RPP1, however this does not raise the issue of which types of technologies are most or more appropriate for Scotland, and what measures may be employed to prioritise them. However in order to maximise the cost and carbon effectiveness of support for these technologies it may be necessary to prioritise funding and resources to those that are most appropriate for Scotland.

Table 5 gives the installed capacity of micro and distributed generation in Scotland for 2008, and Table 6 summaries the typical costs, advantages and disadvantages of these technologies. These are included here to inform the discussion of which of these technologies should be prioritised in Scotland over the short, medium and long terms.

It should be noted that potential future capacity has not been included as in most cases there is no sufficiently robust evidence from which to derive an accurate figure. This is partly because output levels are subject to a very high degree of variation according to local circumstances, which may also change over time.

Table 5: Installed micro and distributed generation in Scotland⁴¹

Technology	Number	Peak Capacity ¹ (kW)	Energy (MWh/yr)	Date of Source ²
Solar PV	95	414	352	Aug 2008
Micro-CHP	16-81	561	-	Dec 2006
Wind	410	771	676	Dec 2007
Micro-Hydro	21	262	1,148	Aug 2008
Solar Thermal	10,700-11,100	22,400-23,400	14,400-15,000	Jul 2008
Biomass	196	3,920	3,360	Aug 2008
GSHP	1,057	6,871	18,091	Aug 2008
ASHP	96	416	1,643	Aug 2008

Notes:

¹Peak capacity is capacity under optimal conditions. Local, seasonal, and other influences will determine actual capacity.

²Approximate.

⁴¹ Element Energy, 2008. Numbers of Microgeneration Units Installed in England, Wales, Scotland, and Northern Ireland. Report to BERR. Available at: <http://webarchive.nationalarchives.gov.uk/http://www.berr.gov.uk/files/file49151.pdf>

Table 6: Comparative advantages and disadvantages of different micro-generation technologies⁴²

Micro-generation technology	Typical costs (UK)	Advantages	Disadvantages
Solar thermal	£2,000– £4,500	Significant potential capacity in Scotland (unused roof spaces) Solar resource is relatively reliable and predictable Proven technology Low cost (compared to other renewables) Some systems also powered renewably (e.g. solar PV powered pump) Proven/established technology Visually unobtrusive Provides hot water all year round (however will not meet demand in winter) Low maintenance	Some systems require grid electricity supply Low cost-reduction potential due to established designs Not suitable for integration with combi boilers without storage
Solar PV	£6,000– £15,000	Significant potential capacity in Scotland (unused roof spaces) The solar resource is relatively reliable and predictable Proven and advancing technology, with significant potential for further cost-reduction Visually unobtrusive Low maintenance	Relatively high capital costs Not generally cost effective without subsidies / incentives
Micro-wind	£3,000– £5,000	Proven technology, with some potential for increased efficiency Can be relatively inexpensive when situated appropriately Matches loosely with daily variations in	Very site-specific resource, particularly in urban areas Least predictable intermittent renewable Lack of available performance

⁴² Adapted from a forthcoming book by the authors. Sources include:

Allen SR, Hammond GP, McManus MC. 2008. Prospects for and barriers to domestic micro-generation: A United Kingdom perspective. *Applied Energy*, **85**, pp. 528-544

MacKay D. 2011. Sustainable Energy Without the Hot Air. (Updated online version)

EST, 2011. Ground source heat pumps. Available at: <http://www.energysavingtrust.org.uk/scotland/Generate-your-own-energy/Ground-source-heat-pumps?gclid=CMW05JXTmqwCFYEZ4QodRV03Og>

EST, 2011. Hydroelectricity. Available at: <http://www.energysavingtrust.org.uk/Generate-your-own-energy/Hydroelectricity>

Scottish Government, 2008. Scottish Hydropower Resource Study.

Stephens E. 2011. The Potential for Exploiting Geothermal Energy in Scotland. Available at: http://www.st-andrews.ac.uk/~wes/research/Geothermal_overview.html

DECC, 2011. Air Source Heat Pumps. Available at: http://www.decc.gov.uk/en/content/cms/meeting_energy/microgen/ashps/ashps.aspx

US DoE. Heat Pump Systems. Available at: http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12610

		energy demand Wide scale of installations / outputs available	information Some opposition (e.g. due to visual impact) May be subject to local building / planning regulations (e.g. due to noise / vibration issues)
Ground-source heat pump	£8,000– £17,000	Very reliable – ground temperatures are constant and predictable Cost effective within the current market Potential in more urban areas of Scotland could be improved through connecting housing to GSHP loops installed under public, community or commercial buildings	Residential densities and the numbers of flats limit the potential in urban areas in Scotland Retrofitting can be problematic (most effective with under-floor heating) Requires relatively large electricity supply Land requirement for ground-loops Limited applicability in densely-populated areas due to impact on ground temperatures High capital costs Installation as retrofit requires significant disruption
Air-source heat pumps	£5,000- £10,000	Can provide hot air or water for heating Good potential for installing new capacity on tenements / flats Air is a free and unlimited resource Widely applicable, including as retrofits, so high potential for emissions reduction	Requires an electricity or gas supply Units may be visually obtrusive when retrofitted (similar to air-conditioning units)
Geothermal	£3,000 - £6,000 for small scale (estimated from US figures and excluding non-build costs)	Provides an almost uninterrupted supply (higher than for even fossil fuel plants) Low maintenance and low cost of operation Long term sustainability of extracting heat from geothermal hot spots has been demonstrated	Little potential in Scotland at small-scale, but possible potential at large scale Highly location-dependent resource Significant costs incurred for identifying new geothermal hotspots
Micro and Community CHP and Biomass	Micro - approx. £3,000 Community - varies widely according to scale and infrastructure costs	Significant untapped potential in Scotland, which could also aid the alleviation of fuel poverty Has the potential to reduce CO ₂ emissions related to fossil fuel use through efficiency gains Technologies at or nearing cost-effectiveness under current market conditions Biomass can be used as a fuel source Community-scale applications can provide low (or no) cost heating to large urban areas Relatively short payback periods, even at community scale	CHP units currently commonly fossil-fuel powered Has an inflexible heat to power generation ratio, which can be problematic if this does not match the respective demands Noise levels for domestic units may be unsuitable for some small homes / flats Carbon savings appear to be less than originally predicted Some localised pollution concerns Lack of available performance information Use of biomass requires fuel to be available locally Land area required for growing biomass fuel is a cause for concern Community-scale application limited by the availability of suitable locations

Anaerobic digestion	£100k - £2m - for example £150k for a 25kWe agricultural waste AD plant - but varies by scale and waste sources	The nature of Scotland's economy and resources mean AD is an appropriate technology with significant untapped potential Utilises waste to generate heat and / or electricity May divert waste from landfills Solid and liquid by-products can be used as fertilizer Integrates waste management from a wide range of sources (domestic, agriculture, etc) with energy generation (and CHP) High costs offset by high revenues	Requires a sufficient and reliable waste stream Quality (and toxicity) of by-products depends on quality of waste May divert waste from recycling streams May cause local odour problems
Micro-hydro	Average £25,000 for a 5kW system, but highly variable	Significant untapped potential in Scotland High energy yields possible Proven technology High potential for expansion in many countries Reliable resource, but varies seasonally Wide scale of installations / outputs available Can be cost effective within the current market, even given high capital costs	Site-specific resource Application limited by the availability of suitable locations May be subject to conservation legislation

The nature of Scotland's geography and its strong division between urban and rural areas means that measures to prioritise the uptake of these technologies must be sensitive to the resources available in distinctly different areas. With the probable exception of geothermal, which is included here because some resources may be available but at some cost, all are likely to have some role to play in Scotland's energy future. The question is where the priorities for increasing uptake should lie.

From a technological perspective there are obvious gains to be made from increasing support for solar thermal and photovoltaics, especially in urban areas with large untapped resources of roof space. Solar thermal also has the benefit of providing cheap efficiency gains, whilst increasing support for solar PVs may have benefits to research and development of the technology in Scotland, and both will have benefits to the economy. The case can similarly be made for micro wind and hydro in rural areas, with the latter also having potential in some urban areas. Evidence for the general potential of wind in urban areas is mixed but insufficient to recommend its immediate value in urban areas.

Ground and air source heat pumps also show significant potential across Scotland, and although GSHPs are much less appropriate for denser urban areas there is clear potential for community scale applications. Micro and biomass CHP as well as anaerobic digestion are discussed separately in Section 8.2 given their significant potential in Scotland, including connection to CHP infrastructure. Further discussion of these technologies can also be found in Section 6 on grid decarbonisation.

6. Grid decarbonisation

The single greatest risk to achieving Scotland's emissions reduction targets, not just from housing but across the whole economy, is that of failing to sufficiently decarbonise the National Grid. The

significance of this challenge is illustrated in Figure 4, taken from the Scottish Soil Framework. Whilst it is beyond the scope of this report to provide a full assessment of energy generation post 2022 the future trajectories of emissions from housing and energy generation are inextricably linked, and will become even more so as contributions from micro-generation and building-integrated renewables increase.

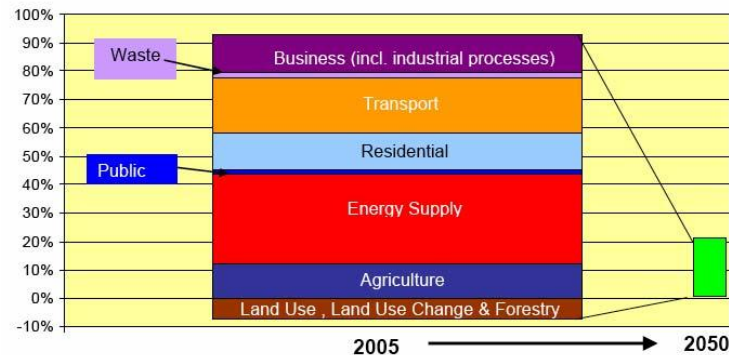


Figure 4: Total net GHG emissions in 2005 in Scotland by sector, compared to the target for total net emissions in 2050⁴³

The following figures and tables are included to illustrate progress to date, future potential, and the scale of the long term challenge.

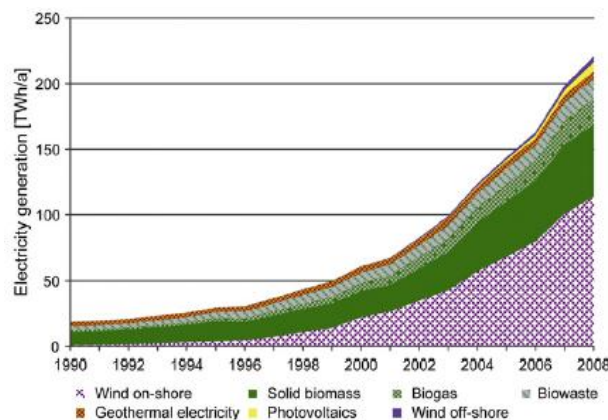


Figure 5: Development of new renewable energy systems for electricity in the EU-27⁴⁴

⁴³ Scottish Government, 2009. The Scottish Soil Framework

⁴⁴ Haas R, Resch G, Panzer C, Busch S, Ragwitz M, Held A. 2011. Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources e Lessons from EU countries, *Energy*, **36**, pp. 2186-2193

Table 7: Minimum and maximum supply limits in 2020 for Scotland plus share in 2007 generation mix (% of total Scottish electricity generation in 2020 for each technology)⁴⁵

	2007 shares in generation	Supply limits in 2020	
		Minimum	Maximum
Wave	0	0	10.5
Tidal	-	0	5
Onshore wind	5.5	5	35
Offshore wind	0	2	15
Nuclear	25.6	0	20
CCGT	26.2	0	25
Pulverised fuel	28.7	0	35
Hydroelectric	12.2	0	15
Biomass	1.8	0	5
Pulverised fuel with CCS	-	0	35
CCGT with CCS	-	0	25

Note:

The selection of maximum and minimum supply limits for the eleven technologies shares' in the Scottish electricity generation mix are necessarily subjective. The maximum refers to the highest figure seen across four recent scenarios for future Scottish electricity mix developed by the industry and the Scottish Govt. (Scottish Council for Development and Industry – SCDI⁴⁶, Scenario by Garrad Hassan⁴⁷, Scottish Energy Study – 'Central' price alternative and 'High' price alternative⁴⁸). The minimum share is set be zero where the output of a technology could be removed from the electricity network in Scotland, as would happen for planned outages at thermal stations, or periods of zero renewable energy resource, for instance.

The main challenge will be enabling a transition from generating electricity from fossil fuels to near 100% renewables by 2050 without being sidetracked by any revival of non-renewable or low carbon but unsustainable forms of generation. It will also require investment in restructuring the grid for a rapid up-scaling of distributed renewable generation, both for more centralised renewables such as wind farms and wave power and for distributed micro-generation such as solar, community wind turbines, and micro-hydro. If the building stock is to be part of the carbon solution, rather than a problem, moving to a decentralized energy system, where there is substantial micro-generation, could be an important strategy⁴⁹.

Looking further ahead, a key concern is the uncertainties over the future of gas supplies and prices, and need to ensure energy security at a national level. Insuring against these uncertainties without risking later reliance on importing electricity from less decarbonised countries will necessitate support for, and connection to, the proposed European Supergrid. The Supergrid

⁴⁵ Allan G, Eromenko I, McGregor P, Swales K. 2011. The regional electricity generation mix in Scotland: A portfolio selection approach incorporating marine technologies, *Energy Policy*, **39**, pp. 6–22

⁴⁶ Scottish Council for Development and Industry, 2009. The future of electricity generation in Scotland. Report prepared by Wood Mackenzie for SCDI, 9 December 2008

⁴⁷ Murray B. 2009. The power of Scotland renewed. Based on research conducted by Paul Gardner of Garrad Hassan, supported by Friends of the Earth Scotland, RSPB, World Development Movement and WWF, July 2009

⁴⁸ AEA Technology, 2008. Scottish Energy Study, vol. 5: Energy and Carbon Dioxide Projections for Scotland. Prepared for the Scottish Government, released October 2008

⁴⁹ Herring H. 2009. National building stocks: addressing energy consumption or decarbonization? *Building Res. & Info*, **37**, pp. 192–195

should also enable Scotland to benefit economically from its renewable resources at times of excess supply.

However whilst the scale of the problem appears great, the potential for Scotland to overcome it is even greater. The solutions can be expected to have much wider benefits to the economy and society.

Scotland's total electricity consumption is predicted to reach 43TWh by 2020, with a target of meeting 100% of this demand equivalent (and 30% of total energy consumption) from renewables, whilst creating up to 40,000 new jobs and securing investment of £30 billion in the Scottish economy⁵⁰. A growing number of studies have found this to be both achievable and exceedable using currently available technology – for example, and accepting the intermittency of the resource and discounting potential in areas governed by environmental and MoD restrictions, the potential for onshore wind alone has been calculated to be 45TWh.

The potential for other centralised renewables is also highly significant, with potential to generate 82TWh from offshore wind, 45.7TWh from wave power, 33.5TWh from tidal streams⁵¹. Although the potential for further large scale hydro beyond projects such as Glendoe and the pumped storage schemes proposed for the Great Glen is now very limited.

Additional electricity supply, particularly in more remote areas, could be generated from a range of small scale renewables, particularly by realising the existing potential of 2.98TWh (baseline scenario) for micro hydro schemes, enough to provide power for almost 600,000 homes⁵².

Underlying these figures are a range of caveats, including the status of the technology (for wave power), potential ecological impacts (for tidal power), public acceptance (onshore and near-shore windfarms), and the technical, environmental and economic issues around large-scale grid restructuring. However, in the long term none of these appear completely insurmountable for matching supply with predicted demand, and particularly when considering the additional potential from smaller scale community renewables and micro-generation.

In conclusion, the currently available evidence is sufficient to state that Scottish targets for electricity generation from renewables are technologically, economically, socially, and politically achievable.

As an aside, during the production of this Interim Report the authors note that a new report by the Institution of Mechanical Engineers⁵³ on the future of energy in Scotland has received some attention in the media. Having considered this with respect to the other evidence reviewed as part of this study, and although it contains many salient points and may be a useful primer on the subject, it appears to add little that is new to the current debate.

In addition, just prior to the publication of this report the Westminster government announced £103m of new funding for renewables in Scotland. At the time of writing the exact details of this

⁵⁰ Scottish Government, 2011. 2020 Routemap for Renewable Energy in Scotland

⁵¹ RSPB Scotland, WWF Scotland and FoE Scotland, February 2006. The Power of Scotland: Cutting Carbon with Scotland's Renewable Energy

⁵² Scottish Government, 2008. Scottish Hydropower Resource Study

⁵³ IMechE, 2011. Scottish Energy 2020? Institution of Mechanical Engineers

remain unclear, however they appear to emphasise larger scale renewables. This is a welcome development, but in light of the other evidence presented in this report it raises questions as to how best to balance the priorities between spending on big but easier wins with the wider and more complex, but arguably more beneficial, tasks of delivering a low carbon built environment through energy efficiency and micro-generation.

Whilst the immediate priorities for reducing emissions from the Scottish housing stock are energy efficiency and decarbonising energy supplies, one of the two greater, and more long-term, challenges will be providing renewable heat. In the longer term (2022 to 2030 and beyond) the most significant challenge will be meeting the demand gap that will grow as households shift from mains gas to electricity, solar thermal, heat pumps, and micro and community combined heat and power (CHP). Although given the lower proportion of Scottish households with mains gas connections this is likely to present less of a challenge in Scotland than for the rest of the UK.

Looking ahead, the greatest problem for increasing the contribution of renewable heat to meeting the energy demand from Scottish housing will be installing the infrastructure and building services needed to deliver it. However ensuring waste heat from electricity generation is captured and utilised should also be a priority in the run up to 2022 and beyond. The simplest and most effective means of enabling this would be requiring all new power plants, such as the biomass plants proposed for Leith, Grangemouth, Rosyth and Dundee, to be capturing heat and delivering it to local residents and businesses from day one of operation.

The feasibility of heat recovery from existing power plants was recently covered in a report by AEA Technology⁵⁴, which found that significant amounts of heat could be recovered, although the financial returns would be unattractive to investors and direct financial support from the public sector would be difficult to justify. This led AEA to conclude that more prescriptive planning policies based on international best practice should be considered, including a mandatory requirement for the co-location of sources of heat supply and demand; wider integration of district heating into existing policies and programmes; the development of a Code of Practice for district heating; and a proposal for a Scottish Heat Planning Law. The authors recommend that these proposals be given serious consideration.

In light of the additional costs and difficulties of retrofitting CHP infrastructure to existing housing it would be prudent to use the opportunity afforded by the current rate of new build to maximise its availability in areas where providing new housing is a priority between now and 2022. Heat for these could be provided from CHP units installed at the public buildings that would be expected to be constructed or upgraded to meet the needs of new residents, but could also be sourced through partnering with local businesses. In addition, this period represents an opportunity to identify those urban areas in which retrofitting community CHP has greatest potential at the lowest cost, and progressing these as rapidly as feasible.

For 2022 to 2030 it would be advisable to progressively expand community CHP wherever technologically and economically viable, prioritising more densely populated areas, areas where the residential population is growing most rapidly, and areas with high concentrations of fuel poverty.

⁵⁴ AEA Technology, 2011. A study into the recovery of heat from power generation in Scotland. Available at: www.scotland.gov.uk/Resource/Doc/362183/0122534.pdf, accessed 06.12.2011

Thinking beyond 2030 is likely to require a reassessment of progress on renewable heat in general. As biomass-fuelled CHP is a low carbon energy resource it may not be a favourable option in the long term if demand can be met by zero carbon alternatives and a highly decarbonised grid. However for the immediate future its potential to deliver low carbon and low cost heating to large numbers of homes makes it an important measure for tackling fuel poverty.

The other great longer term challenge will be restructuring the electricity grid to meet and adapt to the needs of the future electricity generation mix. The scale, complexity, and levels of investment needed to meet this challenge will require a coordinated strategy that both supports and responds to progress in other priority areas. In the immediate term it needs to balance responding to increases in the number of centralised renewables and low carbon generation plants with the urgent need to support the uptake of micro-generation by upgrading the grid, particularly in urban areas. In light of the increasing reliance on electricity that is expected to result from a move away from gas, priorities for longer term strategies and investment are likely to focus increasingly on ensuring security of supply. Due to the priority for sourcing low carbon electricity it will also be necessary to prioritise measures to ensure any supply gaps can be met at the lowest carbon cost. Therefore given that renewable energy constitutes a higher proportion of the electricity supply in Scotland than the rest of the UK, the most favourable long term option may be integration into the European Supergrid.

7. Behaviour change, adaptation and community empowerment

The importance of delivering effective behaviour change in reducing emissions is widely recognised, as is the need to deliver it across all sectors and sections of society⁵⁵. However this also demonstrates the need for greater understanding, and a strategy that goes significantly further and is more nuanced than the policy initiatives that have sought to target specific public behavioural changes in the past. Such a strategy should also take into account the widely different attitudes towards climate change, and therefore enabling effective behaviour change also requires understanding and addressing these differences. Furthermore, it must be recognised that even those most predisposed to adopting pro-environmental behaviours can behave far from rationally – or conversely, it may be completely rational not to adopt a ‘pro-environmental’ behaviour if the costs and implications of doing so are deemed to be unacceptable, e.g. for financial reasons or any additional time required.

⁵⁵ Scottish Government, 2009. SEABS 08: The Scottish Environmental Attitudes and Behaviours Survey 2008

Defra, 2008. Changing Behaviour. Available at:

<http://www.defra.gov.uk/sustainable/government/what/priority/changing-behaviour.htm>

SDC, 2010. The Future is Local. Sustainable Development Commission, July 2010. Available at: <http://www.sd-commission.org.uk/presslist.php/112/empowering-communities-to-lead-local-improvement-works-is-the-best-way-to-tackle-climate-change-and->

EST, 2008. Towards a long term strategy for reducing carbon dioxide emissions from our housing stock.

DfT, 2010. Behaviour Change: What Works for Transport? Think Piece project. Available at <http://www.dft.gov.uk/pgr/scienceresearch/social/behaviour-changes/>

Highly successful behaviour change initiatives include using seatbelts⁵⁶ and tackling drink driving⁵⁷, speeding⁵⁸ and smoking⁵⁹. However these are single behaviour changes achieved by awareness-raising backed by legislation and new laws, and even for these it is useful to note the length of time each took to take hold.

However how energy efficient a household is the product of many behaviours, as well as the wider demographic and socio-economic context and composition of the household. This complexity means that studies into energy consumption behaviour tend to be split into those that focus on how behaviour influences consumption, and those that study the effectiveness of specific behaviour change interventions (e.g. the plethora of work around designing smart meters).

A key problem for policy makers is that whilst significant gains could be made from targeting known (modellable) behavioural influences on consumption they are generally neither possible nor desirable to influence directly. Conversely, scaling up the results from many studies of behavioural interventions risks over-estimating potential savings for a number of reasons - for example participant self-selection bias, the Hawthorne Effect (the impact on behaviour of the knowledge of being studied), and the replicability of a particular intervention at a much larger scale.

Although research has found that behaviour change can achieve energy savings of 5-15%⁶⁰ it has also found very high levels of variability in the influence of behaviour on heating and electricity and water consumption⁶¹. This underlying complexity and (current) lack of large datasets makes it unwise to scale up the results of specific behaviour change interventions to wider changes in total household energy efficiency – and therefore emissions savings. However there is a wealth of evidence about what works from wider studies on behaviour change – both on specific measures and how to implement them most effectively - that can be employed for reducing emissions from households.

Numerous common themes run through this evidence⁶²:

⁵⁶ Jochelson K. 2007. The role of the Government in public health: A national perspective. *Public Health*, **121**, pp. 1149-1155

⁵⁷ Mann RE, MacDonald S, Stoduto G, Bondy S, Jonah B, Shaikh A. 2001. The effects of introducing or lowering legal per se blood alcohol limits for driving: an international review. *Accident Analysis & Prevention*, **33**, pp. 569-583

⁵⁸ Pilkington P, Kinra S. 2005. Effectiveness of speed cameras in preventing road collisions and related casualties: A systematic review. *British Medical Journal*, **330**, pp. 331-334

⁵⁹ Adshead F, Thorpe A. 2007. The role of the Government in public health: A national perspective. *Public Health*, **121**, pp. 835-839

⁶⁰ Martiskainen M. 2007. Affecting Consumer Behaviour on Energy Demand. Final Report to EdF Energy, Sussex Energy Group, Brighton

⁶¹ Gill ZM, Tierney MJ, Pegg IM, Allan N. 2010. Low-energy dwellings: the contribution of behaviours to actual performance, *Building Research & Information*, **38**, pp. 491 — 508

⁶² Sources include:

Defra, 2008. A Framework for Pro-environmental Behaviours

Energy Saving Trust, 2010. Energy in the Home: A selection of insights into consumer behaviour. Presentation to the Scottish Government, 28th June 2010

Scottish Government, 2009. SEABS 08: The Scottish Environmental Attitudes and Behaviours Survey 2008

Department for Work and Pensions. 2009. Incentives to save for retirement: Understanding perceptions and behaviour

- Facilitating conditions for behaviour change is at least as important as trying to influence it directly
- Behaviour change is most effective when a number of levers are pulled in a coherent, co-ordinated and systematic way
- Government, and its wider partners, need to be seen to be leading by example
- Behaviour change needs to be coordinated across sectors and sections of society
- Changing social norms is key, whether this is through provision of infrastructure and services or through regulation
- Interventions are most effective when tailored to the local / community level, or to specific groups of people
- Targeting multiple contexts, moments of lifestyle transition and institutional or infrastructural pressure points is effective
- Policies aimed at changing behaviour need to be simple and transparent
- Climate change is generally not a useful motivator, and for some will have the opposite effect
- Positive images of pro-environmental behaviour to promote non-environmental messages are effective
- Awareness-raising and information provision alone does not work effectively, but does work better when tailored to the target audience
- Knowing and responding to the target audience is essential for success
- The messenger must be trusted by the target audience
- More needs to be done to develop behaviour change initiatives in parallel with technological change in order to maximise the benefits of both
- The effectiveness of financial interventions partly depends on the ability of people to gauge their future circumstances, and this is particularly difficult when their current financial situation is unpredictable
- Feedback, e.g. from home energy surveys or the displays on smart meters, needs to be designed to prompt action - e.g. most households will be more receptive to financial savings than energy / emissions savings
- Greater cumulative outcomes can be achieved by targeting mutually reinforcing behaviours
- Ideally, a substitute behaviour needs to be more attractive than the default

Whilst this list is extensive and the number of schemes and projects aimed at changing energy consumption behaviour is now growing the field is still relatively new and poorly understood. This presents significant opportunities for research, innovation and creativity that should yield further emissions reductions.

Another challenge here is how to reinforce such behaviours so they 'stick' over the long term and become habits rather than conscious actions. For example, remembering to switch off unused

Consumer Focus Scotland, 2010. The role of regulation in driving behaviour change. Presentation to the Scottish Government, June 2010

Scottish Government, 2010. 10 Key Messages About Behaviour Change

Scottish Government, 2011. International Review of Behaviour Change Initiatives

Scottish Government, 2011. Review of the Climate Challenge Fund

lights and appliances⁶³. The evidence for how long any given intervention 'sticks' is limited and contested especially in the case of reported behaviour. Therefore it may be more useful to prioritise single behaviour changes that do not require regular repetition but which may reinforce other behaviours, such as the purchasing of energy efficient appliances, whilst progressing the development of effective attitudinal interventions.

This need to address attitudes as well as behaviours is recognised in the RPP1 report (para 4.30) in relation to improving property and stimulating the demand for energy efficient homes. However it remains unclear what measures are being considered beyond awareness-raising and financial incentives. In the absence of regulation such a standpoint may be justified in the context of prioritising the uptake of physical interventions such as installing insulation, however the longer term approach to reducing household emissions must employ a much wider range of methods and identify appropriate and acceptable opportunities for regulatory interventions. The former should include expanding local education and community empowerment initiatives, and encouraging greater creativity and innovation in these, whilst the latter should include influencing consumer behaviour beyond the current scope of regulations and incentives.

The delivery of information and support for energy efficiency measures, micro and small scale generation, and behaviour change is likely to come from a range of sources including government, the public and third sectors, industry, and communities themselves (see also Sections 7.3 and 8.2.3).

7.1 Adaptation

Adaptation behaviour is a distinctly different area of study, however as they are also habitual behaviours effective changes are likely to be deliverable using the same toolkit of 'what works' (although we make no claim that this list is complete as this is a rapidly evolving field). In the context of priorities for energy and housing there are two key adaptive responses to consider: adaptation to energy prices rises; and adaptation to different / changing thermal environments.

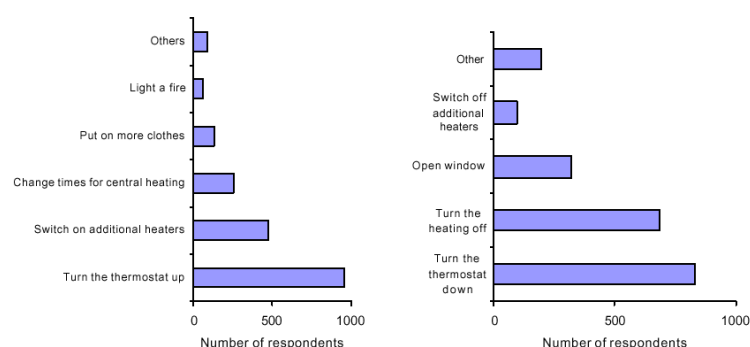


Figure 6: Behaviour in response to feeling too cold (left) and warm (right)⁶⁴

⁶³ Jackson T. 2005. SDRN Briefing Note One: Motivating Sustainable Consumption. Sustainable Development Research Network publication. Available at: www.sd-research.org.uk/wp-content/uploads/sdrnbriefing1motivatingustainableconsumption_001.pdf

⁶⁴ Department of Trade and Industry, 2003. Energy – its impact on the environment and society. Annex 3a

As discussed previously the benefits of energy efficiency interventions to poor quality housing are usually largely or wholly realised as warmer homes rather than lower energy consuming ones, however common adaptation behaviours can still present a barrier to reducing energy demand even once a household is able to attain their desired level of warmth. In an ideal energy-conscious society the first adaptive response to feeling too hot or cold at home would be to add or remove clothing, however research conducted for the Department of Trade and Industry in 2003 found this can be far from the case, as shown in Figure 6.

Whilst the responses to being too warm indicate respondents behaving optimally (from an energy point of view), the low ranking of putting on more clothes as a response to feeling too cold is consistent with the wider evidence on behaviour presented in this report, and is problematic for modelling behaviour and how it influences energy demand. Although there is a wealth of research on human responses to differing thermal environments there remains the problem of being able to accurately model their impact on energy demand (see also Section 4.3.1). However recent research into non-air conditioned buildings has indicated how this knowledge gap may be closed by the inclusion of other environmental stimuli (for example relative humidity and CO₂ levels) and different occupancy regimes, and by using probability to predict human priorities in choosing adaptive behaviours (for example whether a behaviour will have other positive or negative effects)⁶⁵.

However despite the uncertainties over modelling the impact of adaptive behaviours on energy demand there is still good evidence that giving occupants greater control over their energy consumption at least results in them behaving more optimally⁶⁶ (which makes modelling easier) and some evidence to link this to demand reduction⁶⁷. In light of this and other evidence it seems logical to recommend that the scopes of energy efficiency schemes include increasing support for installing measures that enable greater control over indoor environments, and that further provisions to promote their installation could be made under the Building Regulations and other standards.

The evidence for how households are responding to energy price rises, and their impact on energy demand, appears less conclusive and requires further research. Recent research from Denmark suggests that cost is not a strong factor in influencing the way occupants use their homes⁶⁸, however obviously the Scottish context is somewhat different and it may be informative to conduct a similar study here. However adaptation to energy prices rises is a different form of behaviour than adapting to thermal comfort, in that the former requires anticipation of receiving a higher energy bill at some point in the future to trigger single and / or habitual behaviour change; whilst the latter is a habitual response to change as it is experienced⁶⁹. This suggests there will be a lag between households receiving higher energy bills and their decision to adapt and may

⁶⁵ Wei S, Buswell R, Loveday D. 2010. Probabilistic modelling of human adaptive behaviour in non-airconditioned buildings. Proceedings of the Network for Comfort and Energy Use in Buildings (NCEUB) Conference, *Adapting to Change: New Thinking on Comfort*, Windsor, April 2010

⁶⁶ Baker KJ, Rylatt M. 2008. Improving the prediction of UK domestic energy demand using annual consumption data. *Applied Energy*, **85**, pp 475-482

⁶⁷ Boerstra A. 2010. Personal control in future thermal comfort standards? Proceedings of the Network for Comfort and Energy Use in Buildings (NCEUB) Conference, *Adapting to Change: New Thinking on Comfort*, Windsor, April 2010.

⁶⁸ Frontczak M, Andersen RV, Wargocki P. 2010. Questionnaire survey on factors influencing comfort with indoor environmental quality in Danish housing. *Building and Environment*, **50**, pp. 56-64

⁶⁹ Stern PC, Young OR, Druckman D. 1992. *Global environmental change: Understanding the human dimensions*. National Academy Press, Washington, D.C.

help explain the recent reports of low numbers of consumers switching energy suppliers, but it remains unclear how different households are responding (and will in future), and best to trigger the most desirable adaptive responses. It also suggests that any increased take up of energy efficiency incentives in response to higher prices will lag behind them, and there are clear parallels to be drawn with influencing energy efficiency behaviour. As such it seems reasonable to recommend similar approaches be applied here, possibly in combination, however doing so would need to avoid moving consumers onto cheaper energy tariffs that source more from fossil fuels.

7.2 Energy Saving Advice Services and consumer awareness

Energy Saving Advice Services, and in particular the Energy Saving Trust, currently form the UK's backbone for delivering support for reducing emissions from households. Whilst these services, and the methods they employ, may be open to some critique, the more urgent issue is the impact on their future of cuts from Westminster.

Following the initial drafting of this report we have been informed that despite the significant cuts made by Westminster to the Scottish Government will continue to fund the EST's Scottish advice centre network in 2012-13. We also now understand that a review of the EST's services in Scotland will commence shortly, and that during 2012-13 the EST will tender (on behalf of the Scottish Government) for the management of the 5 Scottish advice centres (including providing advice on the Green Deal) for new contracts to be in place in April 2014. These new developments are clearly in line with the evidence that follows, however given the timeframe covered by this report they do not impact on the longer term recommendation to ensure the EST 'brand' remains a signal and consistent point of contact for householders.

As part of the later research conducted for this study an attempt was made to assess the likely impact of the loss of the EST and EST-branded services. Whilst the EST carries out numerous evaluations of other programmes, the latest evaluation of the EST itself that came to light dates back to 2000, and although Hansard notes the reply to a question on the conclusions of this study as being *"the Energy Saving Trust had a valuable contribution to make to the Government's sustainable energy objectives in promoting energy efficiency and that there was a continuing case for funding those objectives that could not be met through other sources"*⁷⁰ we were unable to locate the full document.

The length of time that has passed since this evaluation is in itself enough to recommend a new evaluation of the EST in advance of any changes to be made to it, however it is also informative to consider the wider issue of branding on consumer awareness and perceptions of 'green' products.

In 2007 an extensive international survey of consumer attitudes to 'green' products identified a simple five-stage decision-making process for purchasing, with each stage presenting different barriers and opportunities⁷¹. These are as follows:

1. Awareness – consumers unaware of a product (and its benefits) cannot / will not consider it

⁷⁰ Hansard, HC Deb, 22 May 2003, c889W

⁷¹ Bonini SMJ, Oppenheim JM. 2008. Helping 'green' products grow. *The McKinsey Quarterly*, October 2008.

2. Perception – If a product is perceived negatively it will not be purchased - critically the survey found 'green' products are generally perceived more negatively and / or of lower quality than other products
3. Trust – consumers need to be convinced that the claims made for 'green' products stand up – and critically this applies as much to scepticism from naturally 'greener-minded' consumers (concerned that claims may greenwash) as it does to those predisposed to be ambivalent to or against green purchasing
4. Price – this is a simple value for money judgement, however the survey noted that consumers in the UK expressed a preference for a 2 year return on premiums paid for energy efficient appliance (e.g. TVs and washing machines) whilst this was only possible for around 30% of appliances on the market
5. Availability – any consumer preferences for greener products may be negated if these are hard to find.

Whilst further interpretation of these results needs to consider different national contexts and attitudes to different product types, a further finding stands out in the levels of awareness and positive attitudes towards the Energy StarTM label developed by the US Environmental Protection Agency. Energy Star (and to a greater or lesser extent other labels) has been highly successful in addressing the barriers posed by stages 1 to 3, and is almost certainly the most internationally well-known 'green brand'. Furthermore, and in theory at least, if stages 1 to 3 are addressed effectively increased demand should lead to lower prices and / or better value for money, and higher availability. Similar research conducted specifically in the UK also points to these early stages as being critical for influencing consumers to purchase green products⁷².

Whilst obviously the EST has not gained a similar level of exposure globally it is a prominent brand within the UK, and its key functions serve to address the same barriers. For these reasons, and notwithstanding the likely benefits of a new evaluation of the EST with a view to improving the cost and carbon effectiveness of its services (including a specific assessment of its brand awareness), it would seem wise to safeguard its future as a public-facing organisation.

7.3 The Climate Challenge Fund, community empowerment, and climate change communication

Many of the valuable lessons that can be drawn from the 2011 review of the Climate Challenge Fund⁷³ have been presented in the main section on behaviour, however a key finding from the CCF review is its effectiveness in delivering single behaviours such as installing energy efficiency measures, and this may need consideration with respect to future of other new or existing services and initiatives.

Despite the successes of the CCF in delivering single behaviour changes it may or may not be the case that the future funding of CCF projects should prioritise those aiming to work in this area, given that an established 'route' already exists in the form of energy efficiency advice services (albeit one that works in partnership with the CCF). The previous section has outlined the known (potential) strengths of retaining these services (particularly the EST 'brand') in order to influence

⁷² Heinrich M, Neuhoff K. 2006. Choosing to save. University of Cambridge publication. Available at: <http://www.eprg.group.cam.ac.uk/wp-content/uploads/2008/11/eprg0630.pdf>

⁷³ Scottish Government, 2011. Review of the Climate Challenge Fund

single behaviours, but these are focused on influencing consumer choices rather than wider attitudinal and lifestyle changes. Therefore In light of the potential to use the CCF as a resource for promoting more innovative projects, establishing community renewable generation projects, and tackling more complex behaviours that might benefit more from a community empowerment-focused approach.

An additional source of evidence that adds weight to this suggestion is the results of a forthcoming report on the environment and children's health⁷⁴. A key finding from this report is the discussion of the roles of willingness and community capacity in delivering positive socio-environmental change. The report concludes that the evidence indicates significant scope for capacity building in disadvantaged communities, and in many cases there is a great willingness amongst their residents to engage in positive action. Conversely, the CCF review acknowledges that participation in CCF projects to date has been strongly biased towards those already pre-disposed to pro-environmental behaviours and community empowerment – again this is not a criticism but a predictable outcome at this early stage. Therefore it would seem useful to prioritise the development of CCF projects and other initiatives or schemes that could maximise the 'spill-over' of benefits to those communities where willingness may exist but capacity is lacking. However doing so effectively may need greater understanding and communication of 'what works' (see Sections 7 and 8.4).

Further research is also needed on the benefits and impacts of climate change communication initiatives, such as that run by Historic Scotland (and mentioned in RPP1), in order to close the gap in knowledge between how to effectively communicate 'what works' and how that communication translates into personal actions. The limited available evidence on this suggests that the more devolved and personalised approaches pioneered through schemes such as the CCF are more effective, and that attempting to reach wider audiences (for example interviewing a rock band about climate change on a music TV channel) is less likely to result in personal action⁷⁵. However it is exceedingly problematic to untangle the effects of 'low level' awareness-raising activities, such as advertising campaigns, on stimulating (or otherwise) energy efficiency or other pro-environmental behaviours, and therefore their potential benefits cannot be discounted where used effectively and in combination with other levers.

Finally, the evolution technology will also have a major role to play in the future of human behaviour, however as humans are as much shaped by the technology they demand as they shape that demand itself, the most successful technologies are those that capitalise on this two way relationship. Doing so will be critical in maximising the effectiveness of a cornerstone of the UK's emissions reduction strategy, the roll out of smart meters.

7.4 Smart meters and better energy management

The term 'smart meter' covers an increasingly wide range of devices used to inform the occupants of a building about their energy consumption and regularly transmit that data to utility

⁷⁴ Environmental Determinants of Public Health in Scotland. Final Report to the Scottish Government due end of 2011

⁷⁵ European Commission, 2010. Evaluation of the Communication Plan on Energy-Climate Change. The Evaluation Partnership (TEP), London.

White TA. 2011. *Climate Change Communications: understanding people's perceptions and evaluating the effectiveness of interventions*. PhD Thesis. Institute of Energy and Sustainable Development (IESD), De Montfort University, UK

companies. Smart meters are can also be used for monitoring gas and water consumption, and more advanced devices can be used to remotely control building services and appliances. The term is also frequently used to include those devices that display consumption data but do not broadcast it beyond the building, which may be justifiable for those meters capable of measuring / disaggregating the energy consumption attributable to individual building services or appliances. The more basic earlier devices with which many people are already familiar do transmit data beyond the home and are more correctly termed 'energy consumption indicators' (ECIs).

Smart meters have two main uses: to provide actual consumption data to utility companies to allow them to issue accurate bills (rather than estimated bills, which are frequently contested); and to inform occupants about how much energy they are using, and what is responsible for this. Providing real time consumption data to occupants has been found to be effective in reducing energy consumption when used either in place of or in conjunction with other behavioural levers⁷⁶. Basic smart meters usually display the amount of energy being consumed, the cost (financially and in CO₂), and how this compares to previous consumption, for example that of the previous day or a monthly average. These meters rely on occupants learning about their energy consumption by switching services / appliances on and off and noting the changes, but more advanced devices (e.g. those that can be linked to home computers) can provide a greater range of data outputs.

Support for the wider roll out of smart meters is based on the plethora of evidence that shows that enabling building occupants to have greater understanding of and, critically, control over their energy (and water) consumption leads to demand reduction and / or optimisation of use⁷⁷. Most importantly, as human behaviour is partly a construct of cultural and societal norms and values, these findings are borne out internationally, meaning that the influence is effective (to a greater or lesser extent) regardless of social and cultural differences.

Many countries around the world are now engaged in programmes to facilitate the mass roll out of smart meters, including Sweden, Italy, the USA, Canada and Australia. In the EU the Energy End Use Efficiency and Energy Services Directive (2006/32/EC) (also known as the Energy Services Directive) requires the installation of basic (real time display only) meters in all new buildings, and when existing meters are replaced. Although market penetration is still relatively low, and studies of the impact of basic meters have not found drastic reductions in consumption, e.g. around 7% in the USA⁷⁶, improvements in design and functionality of the devices show the potential for more significant savings, especially when combined with other technological measures. Four measures that could be combined with smart meters to reduce energy consumption are: programmable thermostats; zoned heating and cooling; remote control of HVAC systems; and outlet-level

⁷⁶ Faruqui A, Sergici S, Sharif A. 2010. The impact of informational feedback on energy consumption: A survey of the experimental evidence. *Energy*, **35**, pp.1598–1608

Wood G, Newborough M. 2007. Energy-use information transfer for intelligent homes: Enabling energy conservation with central and local displays. *Energy and Buildings*, **39**, pp.495-503

⁷⁷ Willis RM, Stewart RA, Panuwatwanich K, Jones S, Kyriakides A. 2010. Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. *Resources, Conservation and Recycling*, **54**, pp.1117–1127

Ueno T, Sano F, Saeki O, Tsuji K. 2005. Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data. *Applied Energy*, **83**, pp.166–183

appliance monitors that can automatically disconnect appliances to eliminate leakage currents⁷⁸. Whilst the current prevalence of these varies by country, they are all mature technologies that could potentially converge with each other and smart meters, and whilst the cost of a combined package for domestic use may be prohibitive at present this is expected to fall as demand increases. Looking further ahead, consumer demand could also be increased by designing systems for even greater levels of remote control - for example by using home wireless networks linked to mobile phones to allow HVAC systems and a wider range of appliances to be switched on and off, possibly even passively in response to locational data from the handset. However, even at present the limiting factors for smart meters are more human than technological: designing displays to be more effective in influencing behaviour and selecting combinations of functions that are the most useful for consumers.

In some countries, the business case for establishing an advanced metering infrastructure (AMI) relies in part on improving consumption feedback to customers and assisting in the transition to lower-impact energy systems. There is an expectation that AMI will lead to reductions in both the demand and the cost to serve customers through improved communication, but little evidence exists to show overall demand reduction. To what extent might smart meters improve the prospects for customer engagement? To assess this question, end-user perceptions and practices must be considered along with metering hardware and economics. Using the theory of affordances, qualitative research is examined to understand how householders have used consumption feedback, with and without smart meters. Although AMI offers possibilities for household energy management and customer–utility relations, there is little evidence to suggest it will automatically achieve a significant reduction in energy demand. For that, there has to be a determined focus on overall demand reduction (rather than on peak electricity demand reduction), on designing customer interfaces for ease of understanding, and on guiding occupants towards appropriate action. Appropriate forms of interface, feedback, narrative, and support will be needed to reach diverse populations.

⁷⁸ Meyers RJ, Williams ED, Matthews HS. 2010. Scoping the potential of monitoring and control technologies to reduce energy use in homes. *Energy and Buildings*, **42**, pp.563–569

Table 8: International status of ‘smart meters’⁷⁹

	Principal motives	Smart metering status	Regulation	Comments
California	Load mgmt. / peak reduction	In progress for electricity, gas ‘piggybacking’	Large local monopolies, vertical integration	Some success with peak reduction; a low but increasing interest in demand reduction; some strong customer resistance
Italy	Fraud reduction; contractual power control/load limiting	Rollout almost complete (electricity)	Slight competition, with ENEL dominant	Payback time of less than five years is claimed; no customer displays as yet
Malta	Fraud reduction, water Conservation	Rollout to begin soon	Monopoly	Demand reduction low down on the list of priorities; no customer displays
Netherlands	Demand reduction, load management	Mandatory rollout halted; terms being renegotiated	Liberalized; networks own meters	Legal challenge on data privacy halted the rollout; customer displays being developed as part of the offer
Ontario, Canada	Load management	Rollout complete; time-of-use pricing now under way	Many local monopolies	Some successes with demand reduction from trials with in-home displays, but they are not rolled out with the smart meters
Sweden	Accurate billing	Rollout complete	Liberalized; networks’ own meters	Some web-based feedback to customers; very few displays

In the short term the planned rollout of smart meters to Scottish households is likely to use technology with much more limited functionality than those that will be in use by and beyond 2030. Current proposals will see smart meters with some additional functionality rolled out to all households by 2019 (beginning in late 2011, however if Article 8 of the EU Energy Efficiency Directive is adopted then this may be accelerated to 2016 and include heat, as well as gas and electricity meters. Beyond this, technological turnover will be needed to maximise the benefits of the evolution of the devices to support emissions reduction goals, and therefore there are still some long term costs to be incurred.

However the history of mobile phones is just one example that shows most humans have a natural desire for tools that make their lives easier, but only when the benefits are clear and when designers get the human factors problems right. At present, the perceived benefits of saving energy are insufficient to persuade all but a few to buy their own smart meters, however if the potential they offer for greater functionality can be realised then it may well be possible to make them market viable without subsidy. Two obvious options, which are under development, are providing greater control over heating, lighting and appliances, and providing this control remotely via a smartphone application. Another area for development that would complement these is greater integration of smart meters into smart building infrastructure that uses sensors and controls to automatically respond to (and learn about) changes in occupant behaviour.

⁷⁹ Darby S. 2010. Smart metering: what potential for householder engagement? *Building Res. & Info.*, **38**, pp 442–457

8. Approaches for the future: 2022 – 2030 and beyond

The discussions above point to opportunities and barriers in the RPP1 both in terms of new and existing buildings, tempered by the devolved/non-devolved nature of responsibilities. The current approaches to fabric improvement, with all their problems, have made a useful start and the momentum need to be maintained. At the same time, new and innovative approaches to grid decarbonisation both in terms of technical approaches as well as scale operations need to be explored. Intelligent use of upcoming technologies already visible within the policy horizons, need to be made. Similarly, the links between environmental attitudes, energy consumption and policy-behaviour-carbon emission need to be captured better. All of these approaches need to be informed by an accurate and realistic estimation of the nature of housing stock and its actual energy consumption patterns.

Based on these we propose the following four priorities for the 2022-2030 period:

1. Accelerate the fabric improvement programmes, especially covering Hard-to-Treat (HtT)
2. Decarbonise the grid at community scale
3. Use smart meters for better energy management
4. Enable better understanding of and support for changing attitudes and behaviour, and better adaptation to change

8.1 Accelerate fabric improvement, especially in HtT properties

Current strategies for refurbishment of building fabric in housing target cavity wall insulation and loft insulation measures in suitable dwellings. These measures offer the most affordable treatments which should reach a significant number of dwellings and deliver significant reductions in energy consumption and associated carbon emissions savings. Because of their possible impact these treatments are seen as a priority and their implementation will tackle “low hanging fruit”. However, in Scotland we have a relatively diverse selection of construction forms in our building stock and a wide range of exposure conditions. As a result there are many buildings where cavity wall insulation may not be an option and unfortunately alternative solutions with external or internal insulation are more expensive. The reason for potential unsuitability for cavity wall insulation includes:

1. Building not constructed with a cavity wall. There is a significant proportion of the current Scottish housing stock constructed with a solid wall structure, ranging from stone tenements to large panel constructions.
2. The building may have a conventional cavity wall construction but has a high exposure and is considered unsuitable for full cavity fill⁸⁰.
3. The nature of the cavity wall construction is such that there is concern over the consequence of cavity fill. This may be as a result of the state of repair, the quality of the construction, or even the type of construction used.

Once the easily treated cavity walls and loft insulation have been addressed the next priorities for fabric improvement should be targeted as there will still be considerable potential to reduce

⁸⁰ Building Research Establishment, 2002. Thermal Insulation: Avoiding Risks. BRE Report 262, Watford

energy consumption through fabric interventions in the domestic building stock. Identification of these priorities will require a review of the existing building stock and the potential to treat particular elements. The first question should be whether any of the harder to treat cavities are still possible to treat with cavity wall insulation without leading to moisture penetration risks.. DECC commissioned work by Inbuilt Ltd and Davis Langdon⁸¹ to examine the potential for treating hard to treat cavity wall constructions and this reported that there are “significant cost barriers” in dealing with these walls. Because the difficulty in dealing with these walls can be as a result of a variety of factors, treatment by its nature is non-standard. Appropriate treatment might be developed for some of these properties to enable cavity fill insulation to be installed; the potential scope for this in the current Scottish housing stock is not known.

For properties that cannot be treated with cavity fill insulation safely, other options for adding insulation need to be considered. Some general technical observations regarding other possible wall refurbishment options are:

1. Internal wall insulation is possible but usually requires the lining of the structure with a vapour control membrane and by its nature will require electrical sockets and other service penetrations in the external fabric to be adjusted and sealed. Interstitial condensation risk needs to be carefully controlled. For small properties this can reduce internal dimensions and lead to problems with space standards.
2. Rendered external wall insulation and insulated over-cladding both offer a solution which covers thermal bridges, reduces dampness penetration risk and changes the appearance of buildings. However, these are generally the most expensive refurbishment options.

Some parts of the building stock are particularly problematic, for example the still significant numbers of post war non-traditional and systems built housing in the central belt of Scotland, bespoke analysis of these construction types should be employed to determine the suitability of any insulation refurbishment intervention to avoid deterioration risks.

Strategies for tackling these properties are:

1. Insulate and ventilate correctly. The hygrothermal performance of the building and its fabric needs to be carefully considered. Addition of insulation and improvement of fabric airtightness will reduce energy consumption, but can lead to problems with air quality and condensation if the ventilation provision is not considered in parallel. Thermal bridging is an issue of concern not only from an energy perspective but also from the association it has with surface condensation risk and resulting mould; for this reason good detailing is required for remedial treatment of some structures such as steel or concrete frame constructions.
2. External insulation strategies. External insulation offers a robust solution for adding insulation which has the advantages of:
 - Changing the appearance of properties (positive for urban regeneration)
 - Covering over existing thermal bridges

⁸¹ Iwaszkiewicz et al. 2020. Study on hard to fill cavity walls in domestic dwellings in Great Britain. Report to DECC, Ref: CESA EE0211. Available at:
http://www.decc.gov.uk/assets/decc/what%20we%20do/supporting%20consumers/saving_energy/analysis/788-hard-to-fill-cavity-walls-domestic.pdf

- Improving the weather tightness of buildings

However, it is the most costly of current wall treatment options and because of the change in building appearance isn't suitable for listed or other heritage buildings. It also presents a challenge for application to multi-occupant buildings with mixed tenure.

Any overall strategy for improving building fabric insulation will need to consider how external insulation can be included within this. The opportunities it presents in terms of housing regeneration and in improving weather tightness of structures are particularly relevant to parts of the Scottish building stock.

3. Backcourt insulation to reduce alterations to aesthetically significant facades. The nature of many tenement buildings is such that the front elevation was built to a higher quality and standard of detailing than the rest of the building. As a result the back elevation often had poorer quality materials and incorporated less window opening. Effective wall insulation improvements to tenements might consider targeting external insulation treatments to the backcourt areas which should be easier to treat (and therefore less costly), and would at the same time be of less concern to heritage organisations.
4. Stairwell insulation in flats/tenements. Insulation to walls separating dwellings from communal stairwells is often overlooked. Heat loss through these walls can be significant, particularly as insulation is introduced elsewhere in the building. Treatment of these walls is possible and should not be overlooked.
5. Concentrate on high energy users (focus on 'fuel-hungry' households to reduce overall CO₂ emissions – single family houses are the most energy hungry but also the most responsive to efficiency interventions⁸²). Conversely users who use significantly less than typical amounts of energy will yield significantly smaller emissions savings as a result of efficiency interventions.

Once the low hanging fruit of cavity fill and loft insulation upgrade has been treated across the building stock all of the above strategies will need to be progressively implemented as a priority. This may well occur throughout 2022-30 and where necessary beyond. Although the nature of interventions in hard to treat properties makes them expensive to realise, economies of scale can be achieved where extensive numbers of properties are treated through a strategic intervention. There is significant opportunity for finding solutions for the building stock, however, there is currently an absence of detailed housing stock information sufficient to make detailed strategic prioritisation. An early action should therefore be to assess the Scottish housing stock to evaluate the scope for interventions that will have significant impact on carbon savings whilst being sufficiently affordable to implement on a meaningful scale.

8.2 Decarbonise the grid using community level solutions

The message seems to be: to sell micro-generation, sell efficiency first⁸³. In order to be more successful economic and regulatory instruments should focus on producers (house-builders and

⁸²Lomas KJ. 2010. Carbon reduction in existing buildings: a transdisciplinary approach, *Building Res & Info.*, **38**, pp. 1–11

⁸³Herring H. 2009. National building stocks: addressing energy consumption or decarbonization? *Building Res. & Info.*, **37**, pp. 192–195

energy providers) rather than consumers (households). Tighter regulations and perhaps changes to the planning system, are needed to ensure that producers have a responsibility to install decentralised renewable energy systems (DRES) as part of new developments, to enable connection to the grid, to ensure a sustained financial return from investment and revenue is spent on the expansion of new renewable energy infrastructure. This regulatory framework must be under-pinned by substantial funds focused on producers. Greater intervention is needed if DRES is to be included in new housing development⁸⁴

Community scale wind is more efficient than dwelling scale turbines/PV panels. A recent study⁸⁵ in Alberta, Canada compared three configurations of wind turbines to produce a nameplate power of 100 kW, using a 25 year LCC methodology: twenty 5 kW, five 20 kW, or one 100 kW. Life cycle energy, environment and economic aspects were quantified corresponding to a functional unit (FU) of 1 kWh. Life cycle energy requirement for the 100 kW turbine was 133.3 kJ/kWh, about 69% and 41% less than 5 kW and 20 kW turbines respectively. Global warming impact from the 100 kW turbine was 17.8 gCO₂eq/kWh, around 58% and 29% less respective to 5 kW and 20 kW turbines. The acidification (SO₂eq/kWh) and ground level ozone [(VOC + NO_x)/kWh] impacts from the 100 kW turbine were also found to be significantly less. The difference in relative environmental impacts from configurations is found to be less while performing uncertainty analysis, but does not alter the ranking of configurations. At 10% internal rate of return (IRR), electricity price for the 100 kW turbine was 0.21\$/kWh (Canadian Dollar), whereas prices for 5 kW and 20 kW turbines were 65% and 16% higher respectively.

Renewable heat is as much a priority as renewable electricity. This is especially the case in fuel poor homes where affordable warmth (as opposed to renewable energy) remains a high priority. In the absence of major changes to the grid and until such changes are effected, district heating systems can play a significant part in reducing carbon while increasing the affordability of heating. By using a central boiler plant, community heating systems can benefit from competitive fuel purchasing and can utilise alternative energy sources such as CHP or renewables, including geothermal⁸⁶.

The increased consumption of energy services (especially electricity), and the stochastic nature of some of the most promising renewable energies (wind for instance), the challenge is to find the optimal mix of technologies that will provide the energy services, without increasing the CO₂ emissions, but nonetheless ensuring reliability of supply. While it is not yet possible to avoid electricity from the grid completely (hence nuclear or fossil fuel), CO₂ reductions up to 20%, at no extra costs compared to the business-as-usual case, are easily achievable by an optimal mix of community scale renewable generation and an intelligent arrangement of neighbourhood buildings⁸⁷.

⁸⁴ Williams J. 2010. The deployment of decentralised energy systems as part of the housing growth programme in the UK, *Energy Policy*, **38**, pp. 7604–7613

⁸⁵ Kabir MR, Rooke B, Dassanayake GDM, Fleck BA. 2012. Comparative life cycle energy, emission, and economic analysis of 100 kW nameplate wind power generation, *Renewable Energy*, **37**, pp. 133-141

⁸⁶ EST, 2009. Aberdeen City Council: A Case Study of Community Heating. CE 65. London: Energy Savings Trust

⁸⁷ Weber C, Shah N. 2011. Optimisation based design of a district energy system for an eco-town in the United Kingdom, *Energy*, **36**, pp. 1292-1308

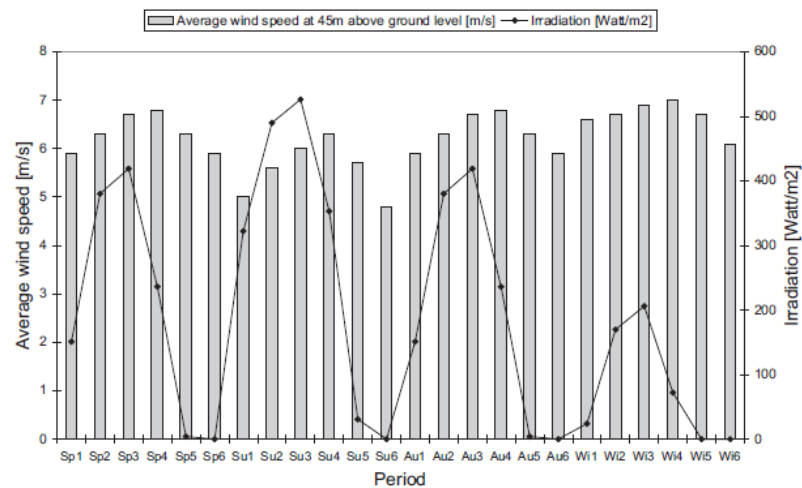
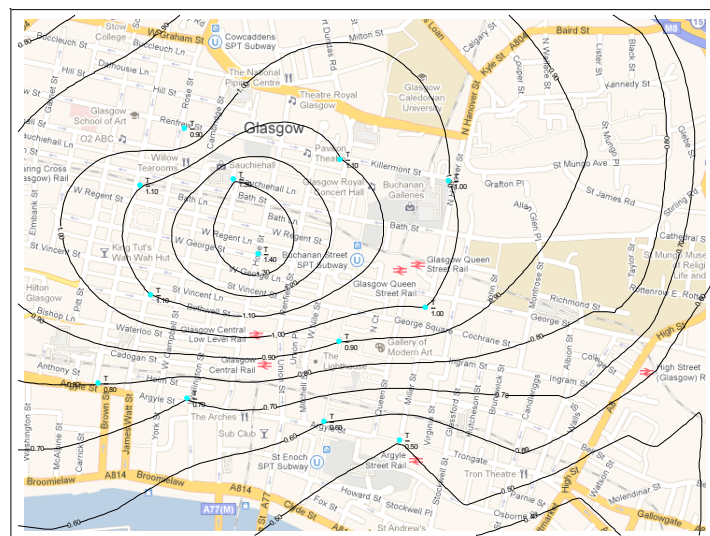


Figure 6: Wind and solar availability in the UK⁸⁷

Cities and large human settlements create their own micro climate (the ‘Urban Heat Island’ effect) which needs to be mapped and suitable spots to take advantage of local warmth identified. In their drive towards sustainable and ecologically sound places all cities, including shrinking cities, will need to consider the local climate implications of their current urban trajectories. While population may decline the underlying urban morphology largely remains in place, leading to the continuation of the urban climate anomaly. In the case of Glasgow for example, this aspect of shrinking is beneficial, in that the urban warmth created by a judicious arrangement of land use / land cover could be exploited for energy efficient uses such as district heating and to enhance the feasibility of low carbon options such as district ground source heating or other communal renewable technologies. Our recent work⁸⁸ shows that the UHI itself does not go away, even in shrinking cities, thereby the opportunities to be sustainable and low carbon might still be available. At the same time, the summertime trends suggest that overheating may become a distinct possibility in the future. These realities should inform shrinking cities in their attempt to re-invent themselves in a carbon and energy efficient fashion.



⁸⁸ Emmanuel R, Krüger E. 2011. Urban Heat Island and its impact on climate change resilience in a shrinking city: the case of Glasgow, UK, Submitted to *Building and Environment*

Figure 7: A heat island mapping exercise in Glasgow⁸⁸

Table 8: Likely barriers to decentralised renewable energy systems⁸⁴

	CERT	Buy Back	RO	LCBP	FIT	2016 Zero Carbon Target	CSH	Plan
Economic								
Investment risk ^a	X		X					
Cost—capital and operational ^b			X	X	X			
Long pay-back period ^c					X			
Lack of value to stakeholders ^d	X	X	X	X	X	X	X	X
Lack of customer demand green energy/DRES					X			
Organisation								
Industrial inertia(house- building and energy industries) ^e	X				X	X		
Lack of ESCOs	X				X	X		
Access to grid								
Information								
Lack of accreditation system for products and service providers							X	
Knowledge transfer								

^aBoth CERT and RO reduce risk particularly to the larger generators but do little for the smaller generators

^bAll RO,LCBP and FIT have the capacity to reduce costs to producers but access to these sources of funding for ESCOs is restricted and is non-existent for house-builders.

^cReduces pay-back period but only for technologies closer to market maturity

^dInstruments which provide some incentive to stakeholders to innovate by providing financial incentive, creating market demand,etc

^eFactors encouraging restructuring in the industries

Economic incentives directed at producers (house-builders and energy industry) rather than consumers would be needed to subsidise capital and operational costs of DRES at least until the market matures.

Strategies to decarbonise the grid and to enhance the potential of renewable heat should include the following:

1. Investigate the technical potential for CHP/DH solutions at specific geographical locations
2. Micro and distributed/decentralised generation (As for DH, but easier due to greater potential with existing infrastructure)
3. Examine the feasibility of changes to planning regulations, including possibly a 'Heat Planning Law',
4. New research and development in heat mapping especially combined with city climate map (following the German 'Stadtklima map' protocols) and pilot schemes

8.2.1 Technical potential for CHP/DH solutions

The Renewable Heat Action Plan for Scotland, published in November 2009 provides a framework action to decarbonise heat as part of the Climate Change Act target of 11% of Scotland's heat to come from renewable sources by 2020. Currently (as of March 2011), the renewable heat

provision in Scotland is estimated to be 2.8% of the non-electrical heat demand⁸⁹. There are several on-going activities in Scotland to decarbonise the heat supply:

- Biomass Action Plan⁹⁰
- Scottish Biomass Support Scheme (now closed for new applications)
- Heat plans for energy from waste plants
- Renewable Heat Incentive for biomass, ground source heat pumps etc⁹¹
- The updated Renewable Heat Action Plan⁹²
- Use of Section 36 consents to encourage heat recovery from biomass power stations⁹³
- Pilot district heating loan scheme⁹⁴
- Identify and utilise opportunities to use anaerobic digestion plants to supply CHP and DH networks

Among the urban areas, Aberdeen City Council is a leader in district heating (via its Aberdeen Heat and Power). The SG has recently awarded a £1m grant to Aberdeen City Council to develop and extend their district heating network across the city⁹⁵.

A recent study⁵⁴ on the feasibility of heat recovery from existing power plant concluded that the following options are technically feasible:

- Target waste heat from industrial processes
- Target landfill sites
- Target off gas clusters (including off gas pockets) where there are good centralised heat loads (such as schools)
- Explore district heating potential where there is a good proximity and mix of supply and demand drivers
- Target large heat loads in individual buildings
- Identify and develop pilot clusters

⁸⁹ Highland Council, 2011. Heat Mapping, Final Report. Available at: http://www.highland.gov.uk/NR/rdonlyres/37863E11-66C1-4F35-9C5C-CFF71FD9BC5B/0/110511_HighlandHeatMap_FinalReport_FINAL_RED_forWebsite.pdf, accessed 07.12.2011

⁹⁰ Scottish Govt. 2007. Biomass Action Plan. <http://www.scotland.gov.uk/Publications/2007/03/12095912/0>, accessed 07.12.2011

⁹¹ Applications to the Ofgem under the RHI Scheme opened on 28.11.2011. Organisations will be able to apply and receive payments on a quarterly basis for heat generated over 20 years. See http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/incentive/incentive.aspx

⁹² Scottish Government, 2011. Update to the Renewable Heat Action Plan. Available at: <http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Energy-sources/19185/Heat/RHUpdate11>

⁹³ Developers of power station proposals under Section 36 of the Electricity Act 1989 need to show they have explored CHP opportunities

⁹⁴ Nearly £2 million in loans to local authorities, housing associations, SMEs and ESCO was awarded in 2011 (see, <http://www.scotland.gov.uk/News/Releases/2011/11/04112708>). A further £5 million has been allocated to allow the scheme to continue. The next round of funding will be announced shortly

⁹⁵ Scottish Govt. 2010. Scotland warms to greener heating. <http://scotland.gov.uk/News/Releases/2010/12/23105100>, accessed 06.12.2011

8.2.2 Micro and distributed generation

Whilst it is not yet possible to comment on the effectiveness of the Community and Renewable Energy Scheme (CARES) or the RHI on increasing the take up of micro and distributed renewables the details of these schemes do address the key issues raised in this report. These changes, along with the Scottish Government's forthcoming Micro-generation Strategy, mean that the immediate future for these technologies in Scotland appears positive, however there remains a need to be mindful of the proposed changes to FiTs.

The impacts of these changes will set the context for the future of micro and distributed generation towards and beyond 2022. At present support for larger-scale distributed renewables is strong and growing and the capacity of (some) communities to develop renewable energy projects is still being realised, however further benefits could occur from engaging those communities where there is willingness but little capacity, as ultimately these may benefit more widely from such projects. More work in this area should be valuable in informing policy post 2022.

In the longer term the biggest technological challenge for increasing capacity is likely to be installing and upgrading infrastructure. Furthermore, the nature of that infrastructure will need to change not only to balance supply from both centralised and distributed renewables, but also to allow for a greater dependency on electricity for heating and the greater provision of renewable heat supplies⁹⁶. However examples from countries such as Germany and the Netherlands are showing how restructuring for renewables can be successfully achieved without deterring new commercial investment⁹⁷, and this report has provided various recommendations on the ways forward for expanding infrastructure for larger scale renewable heat. In addition, the significant potential of solar thermal remains to be tapped, but could be aided by initiatives to retrofit new energy infrastructure into existing buildings.

8.2.3 Changes to planning regulations

A key determinant in promoting renewable heat solutions is the planning law. The most progressive of these planning frameworks is the Danish Heat Planning Law⁹⁸. This requires properties in an area served by district heating to connect to that system. Apart from the fact Denmark had numerous district heating systems in operation before the law came into effect in 1979 there are numerous difficulties in implementing this in Scotland. Chief among them is the incompatibility with competition laws (i.e. the requirement for consumer lock-in) and the lack of co-location (adequate and suitable number of housing units in close proximity to large sources of heat – both exist).

⁹⁶ Britnell J, Dixon T. 2011. Retrofitting in the private residential and commercial property sectors – survey findings. Retrofit 2050 Working Paper. Oxford Institute for Sustainable Development (OISD), Oxford Brookes University

⁹⁷ Swider DJ, Beurskens L, Davidson S, Twidell J, Pyrko J, Prügler W, Auer H, Vertin K, Skema R. 2008. Conditions and costs for renewables electricity grid connection: Examples in Europe. *Renewable Energy*, 33, pp. 1832-1842

⁹⁸ Danish Energy Authority, 2005. Heat Supply in Denmark. Available at:
http://193.88.185.141/Graphics/Publikationer/Forsyning_UK/Heat_supply_in_Denmark/pdf/varmeforsyning_uk.pdf,
accessed 07.12.2011

The following may be considered in the immediate term:

- Single outcome agreements on renewable heat
- Support for consumers switching to DH
- Use public sector as anchor heat load
- Providing funding for feasibility studies
- Apply heat plans in Section 36 consents
- Legislative changes to support infrastructure installation (rights of access to road infrastructure similar to those for other services)

In the medium-to-long term, the following may be necessary:

- Planning in favour of low carbon heat supplies: Include heat infrastructure within National Planning Framework to ease planning burden on proposed development
- Use planning system to locate heat producers near to a heat demand within Strategic Development Plans and Local Development Plans
- New homes could be mandated to receive 'renewable heat'
- Potentially the development of planning policies with mandatory requirements for co-location with existing power plants, drawing on international experience

8.2.4 Heat mapping exercise, City Climate Map and pilot schemes to benefit from them

Heat mapping has rapidly progressed in Scotland in the last 4 years. An initial study to map heat potential was made in 2007 at a resolution of 1km (Scottish Heat Mapping Project⁹⁹). This has now led to plans in several local authority areas with an initial successful heat mapping pilot in the Highland region and funding has been secured for replication of the project in other local authorities¹⁰⁰, and the Scottish Government is providing funding to Fife and Perth and Kinross councils to take forward heat mapping in their local authority areas using the methodology from the pilot undertaken in the Highland Council area¹⁰¹.

Heat Map, created on GIS platforms, could be used across a range of Local Authority functions, especially in the preparation of Local Development Plans to assess and compare site options for development by helping understand the impacts of new development on heat demand within an area as well as test the feasibility of DH for new and existing developments. By linking the map to future demands, development proposals could be evaluated as to their compatibility. Such mapping should become the norm in all Scottish Local Authorities.

⁹⁹ Scottish Heat Mapping Project, 2007. Available at: www.scotland.gov.uk/Resource/Doc/921/0060068.pdf, accessed 06.12.2011

¹⁰⁰ McNaught C, Williams E, Stambaugh S, Kiff B. 2011. A study into the recovery of heat from power generation in Scotland, Report prepared by AEA Technologies for the Scottish Govt. Available at www.scotland.gov.uk/Resource/Doc/362183/0122534.pdf, accessed 06.12.2011

¹⁰¹ Scottish Government, 2011. Update to the Renewable Heat Action Plan. Available at: <http://www.scotland.gov.uk/Topics/Business-Industry/Energy/Energy-sources/19185/Heat/RHUpdate11>

What is now necessary is to link these to City Climate Maps, as in Germany, and to explore the likely impact of climate change scenarios and the effect of urban heat island effects¹⁰².

8.3 Smart meters for efficient building energy management

Building Energy Management Systems (BEMs) and Building Control Systems are becoming a very important area of growth in the 21st century Green Economy. However, the current approach to 'smart meters' in the UK appear to miss the potential for integrating BEMs with smart meter technology, even though such approaches are beginning to be common in some countries, notably in Japan. Such an integration requires many optimized specialties and techniques that span over a wide area of engineering to come together: Network protocols and standards, embedded systems, and Building Standards. Sensor network protocols have not been developed to support all these new data requirements. Specialised low power embedded architecture have to be designed to be integrated with the sensors, operating robustly in different reconfigurable modes. An advanced network sensor platform for management of energy and building control systems has been developed recently by GCU researchers. This architecture will be able to manage many different aspects of building management i.e. energy use, thermal comfort, visual comfort, and security. Current sensor protocols and control systems have been overloaded with new requirements and with its original limitations; it cannot deliver the effective bandwidth required. Optimized control systems using advanced techniques (i.e. neural networks) to develop machine learning agents in the sensor components have been developed. This will generate a system that learns from the environment and human habits of building use. Main technical challenges will be: Stress testing in real world scenario, reflecting human behaviour, and scalability testing.

In the immediate term the planned deployment of energy consumption indicators (basic smart meters) should be supported as set out in RPP1. In the medium term the following should be considered:

- Prioritisation of research and development of intelligent energy management systems ('smart' smart meters) to best facilitate their integration into both the built environment and human lifestyles
- Capitalising on the cumulative benefits of smart meter technologies that have uses beyond energy saving (e.g. remote control of building services and appliances), with a greater emphasis on bridging gaps between the physical and social sciences to solve problems relating to human factors.
- Addressing public concerns over the collection and use of energy data.

In the long term, and assuming a high installed capacity of energy consumption indicators has been achieved, the next step will be building a self-sustaining market for smart meters. This will require smart meters to become aspirational technologies for sale at prices that do not prohibit their sale to the majority of the population. This is likely to be best achieved through a combination of increased functionality and greater integration with building and information technology infrastructure. Education and marketing for these is likely to be needed, particularly amongst the information-poor, which is likely to require further collaboration with energy supplies and trusted sources of information, such as energy efficiency advice services. However greater penetration may be achieved through working with appropriate established brands such

¹⁰² Ren C, Ng E Y-Y, Katzschner L. 2011. Urban climatic map studies: a review. *Int. J. Climatol.* **31**, pp. 2213–2233

as mobile phone companies and high profile individuals (i.e. the iconic names who will produce and / or act as figureheads for smart meter use).

As a note of cautious optimism there is a well-known risk to predicting the long term future of any technology, and technological change may render some or all of the recommendations made above irrelevant by 2030. However, and regardless, the priorities beyond 2030 are likely to be enabling the deployment of the latest smart meter technologies to all households, and supporting their integration with other technologies and services. The speed of technological convergence, as has happened with mobile phones, cameras and mobile computing, may be the primary factor in influencing progress to and beyond 2030.

8.4 Behaviour and attitudinal change and adaptation priorities

In the immediate term the evidence suggests that capacity will continue to grow amongst those most predisposed to pro-environmental behaviour and community empowerment through the CCF and other initiatives. Future initiatives could seek to build on this by drawing on the capacity of 'already converted' communities to support behaviour, lifestyle and attitudinal change in harder to reach communities where public will is evident but capacity is poor. Support should also be directed at the installation of community-owned micro and small scale generation.

Building knowledge and understanding amongst wider society through education and marketing programmes that emphasise the wider benefits of pro-environmental behaviours without focusing on climate change as the primary driver, may prove valuable for reducing energy demand through behaviour and attitudinal change. Homes with a propensity to consume more energy should be targeted using behavioural strategies combined with economic penalties and incentives. On the other hand, homes with low SAP rates should be targeted for whole home efficiency upgrades in order to break through the energy efficiency barrier¹⁰³.

Increasing the understanding of climate change may be better served through schools and lifelong learning schemes. Consider the role of the messenger for these, and consider avoiding using those who may be considered by wider society to have strong and overt green agendas, and support the development and implementation of technologies that save energy but also have useful benefits to householders.

In the run up to 2022 and beyond it may also be necessary to explore publicly acceptable options for future legislation and regulation that could be brought in as the economy recovers, including prioritising the problems caused by tenancy and mixed-tenure housing blocks. A recovering economy may provide opportunities to put in place measures that may be less publicly acceptable during the recession, but these should be planned for and consulted on in advance to identify the most acceptable options and minimise public opposition.

In the longer term it may be advisable to accelerate capacity building and attitude and behaviour change across the majority of Scottish society using a range of measures to normalise these. This could be supported by engaging community leaders in the promotion of positive non-environmental images and benefits of pro-environmental behaviours. In addition appropriate passive building technologies and 'aspirational' consumer technologies, along with the redesign of

¹⁰³ Kelly S. 2011. Do homes that are more energy efficient consume less energy?: A structural equation model of the English residential sector, *Energy*, **36**, pp. 5610-5620

the built environment (in partnership with communities) to facilitate pro-environmental behaviour change, are also likely to have important roles to play.

Beyond 2030 the challenge will be to build on the progress to date, for example by filling in gaps between communities and areas of housing where capacity is stronger, and address those who remain in opposition to reducing emissions. For the latter it may be more effective to emphasise the use of the stick over the carrot, particularly in the case of absentee landlords and those who can bear the financial costs of environmentally profligate behaviours. The key message here is that any medium to long term strategies to be developed for implementation post 2030 will be the last throws of the dice for achieving the 2050 targets, and therefore any and all remaining options should be considered. The Energy Saving Trust's recommendation for the need to "throw everything" at the housing stock is particularly pertinent here, and it would be wise to adopt a precautionary approach that does not rely on emissions savings and other spill-over effects from other sectors.

It may be useful to think of 2022 to 2030 as the last period for understanding and beginning to implement 'what works', and 2030 as the year beyond which the need implement 'what works' country-wide will need to become a higher priority than minimising the economic and public acceptability costs of doing so. However, and with particular respect to behaviour change, adaptation and community empowerment, if sufficient lessons are learnt and capacities are built between now and 2030 it may still be possible to pick such options from a 'war chest', rather than having to employ everything in a last ditch attempt to meet the 80% emissions reduction target.

9. Summary of Recommendations

The following tables summarise the recommendations resulting from this study, along with references to the relevant section(s) of this report. Whilst every effort has been made to reasonably and realistically allocate these to the two timeframes it is accepted that prior progress in all these areas will influence their future prioritisation, particularly given uncertainties of predicting progress further into the future, and the impacts of future economic, environmental, societal and technological changes. For these reasons the list of recommendations for 2022-2030 is significantly longer than that for beyond 2030, and those for beyond 2030 are necessarily more speculative.

9.1. Recommended Priorities for 2022-2030

Recommendations	Section(s)
Identify and target those households who have yet to benefit sufficiently from existing retrofit schemes, particularly those in hard to treat buildings.	3, 4 & 8.1
Use the provisions made by, and consider amendments to, the Climate Change (Scotland) Act and the Tenements Act to use regulation to leverage greater demand reduction, particularly in the privately-rented sector and for mixed tenure blocks.	4.1.5 & 8.4
Increase incentives and widen the scopes of existing and / or new energy efficiency intervention schemes to promote the installation of packages of measures (including microgeneration) to enable increased cost and carbon effectiveness, particularly for tenements and flats.	4.2.3, 4.2.5, 4.3.2, & 8.1
Further enable communities to develop and deliver renewable energy and heating projects, including by leveraging new public and commercial investment.	4.2.5, 5, 7, 7.3, & 8.2
Increase support for the installation of measures that enable greater control over indoor environments, and consider making further provisions under revisions of the Building Regulations and other standards.	4.3.1, 7.1, 7.4 & 8.3

Significantly increase the support for new and upgraded infrastructure for micro and distributed renewable energy generation, with particular respect to retrofitting in areas of higher potential / need.	5, 6, 4.2.4 & 8.2.2
Support the expansion of anaerobic digestion (and connection to heating infrastructure).	5 & 8.2.1
Better enable supporting measures to differentiate between the potentials of different renewable technologies in different locations.	5 & 8.2.2
Enable grid decarbonisation through expansion of centralised and distributed renewable energy, and securing investment in the grid restructuring required to support it.	5, 6 & 8.2.2
Reconsider the evidence for the 'least worst' option for closing the energy demand gap that cannot be met by renewables and must be met by low carbon centralised generation. The recommendation here is nuclear over large scale biomass or coal.	6
Implement single outcome agreements on renewable heat.*	6, 8.2, & 8.2.3
Increase support for consumers switching to district heating.	6, 8.2, & 8.2.3
Introduce legislation to support new infrastructure installation (i.e. rights of access to road infrastructure similar to those for other services).	6, 8.2.1, & 8.2.2
Increase support for innovative behaviour change and community empowerment initiatives that address long term behaviours / lifestyles, as well as those aimed at increasing capacity in communities where it is lacking. The Climate Challenge Fund would be a useful vehicle for delivering this support.	7, 7.1, 7.3 & 8.4
Continue to develop, support, monitor and evaluate behaviour change initiatives, using the latest evidence to inform revisions to their methods and modes of delivery.	7, 7.3, & 8.4
Safeguard the future of the Energy Saving Trust (and other advice networks) to maintain their value (including 'brand' value) but re-evaluate to improve service delivery.	7.2 & 8.4
Support the roll out of smart meters and enable the development of a self-sustaining market for smart meters and intelligent energy management through supporting research and innovation, and encouraging collaboration.	7.4, 8, & 8.3
Monitor and evaluate the impact of the roll out of smart meters and support the future rollout of advanced metering and control infrastructure.	7.4, 8, & 8.3
Consider specifically targeting tenements for installing backcourt insulation.	8.1
Consider specifically targeting tenements and flats for insulation in communal areas.	8.1
Consider targeting 'fuel hungry' households where more potential for demand reduction may exist.	8.1
Apply heat plans in Section 36 consents.	8.2.1
Use the public sector to anchor heat loads.	8.2.3
Plan in favour of low carbon heat supplies - include heat infrastructure within National Planning Framework to ease planning burden on proposed development	8.2.3
Use the planning system to locate heat producers near to a heat demand within Strategic Development Plans and Local Development Plans.	8.2.3
Mandate the provision of renewable heat to all new housing.	8.2.3
Develop planning policies with mandatory requirements for co-location of new sources of heating demand with existing power plants, drawing on international experience.	8.2.3
Increase the provision of funding for feasibility studies and heat mapping for renewable heat.	8.2.3 & 8.2.4

*Renewable heat is defined as including combined heat and power (CHP) and district heating (DH) fuelled by biomass or anaerobic digestion, but may include gas where there is a commitment later to conversion to either of these sources. It also includes distributed renewables such as solar thermal, ground source heat pumps (GSHPs) and air source heat pumps (ASHPs).

9.2. Recommended Priorities for Beyond 2030

Recommendations	Section(s)
Address any outstanding areas of concern in relation to the achievement, or otherwise, of the 42% by 2030 target, and identify successes and failures in relation to reducing emissions from Scottish housing.	3, 4, & 8.1
Consider significant redevelopment of any remaining problematic areas of existing build.	3, 4 & 8.1
Build on the evidence of 'what works' to increase the capacity of communities to deliver further attitudinal and behaviour change, as well as new community-led renewable energy projects	4.2.5, 5, 7, 7.1, 7.3, 8.2 & 8.4
Accelerate the deployment of renewables on remaining existing build.	5 & 8.2.2
Further expand and CHP and DH networks upgrade gas and biomass-fuelled plants for lower carbon fuel sources if and as they become readily available.	5, 6, & 8.2
Insure against the impacts of prices rises, energy security risks, and importing higher carbon energy, whilst enabling trade with other producers of low carbon energy, through integration with the European Supergrid.	6
Support the development and expansion of advanced metering, control and communications technologies, including the necessary infrastructure, to enable greater market penetration and maximisation of the benefits of intelligent energy management.	7.4, 8, & 8.3

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