centre for sustainable energy

The value case for decarbonising homes in Wales: literature review findings

A report to Welsh Government housing decarbonisation team

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Executive summary

The Welsh government has committed to ambitious targets to achieve net zero emissions from Welsh homes by 2050, requiring significant investment in actions to decarbonise existing homes and the electricity and heat supply to them. The Welsh Government is keen to ensure that such investment also contributes towards wider goals to tackle fuel poverty and generate other benefits towards a prosperous, green and equal Wales.

This report presents evidence on the co-benefits from decarbonising homes relevant to the Wales Wellbeing Act and Prosperity for All goals as identified in a rapid evidence assessment of 61 relevant good quality studies.

Evidence of the co-benefits towards achieving the Welsh wellbeing goals

The list below provides an overview of the co-benefits identified as contributing towards each well-being goal and a judgment on the quality of the evidence reviewed.

Wellbeing goal:	**A prosperous Wales**
Co-benefits:	Strong evidence of range of benefits for: a low carbon economy; GDP growth; tax receipts; savings to Treasury, creation of decent, local jobs; local supply chain; training; savings on fuel bills; increases to property value.
Quality of evidence:	**Good**

Wellbeing goal:	**A resilient Wales**
Co-benefits:	Strong evidence of benefits for: increased local economic resilience; increased social capital; grid reliability; and energy security. Mixed evidence on futureproofing homes against the effects of a changing climate. Weaker evidence on local environmental benefits.
Quality of evidence:	**Good**

Wellbeing goal:	**A more equal Wales**
Co-benefits:	Strong evidence of benefits for tackling fuel poverty and associated health, economic and social equality benefits. Weaker evidence on educational benefits.
Quality of evidence:	**Good**

Wellbeing goal:	**A healthier Wales**
Co-benefits:	Strong evidence of health benefits from improved housing for mental health, health of people with existing respiratory conditions; health inequalities and wellbeing. Weaker evidence on savings to NHS and social care.
Quality of evidence:	**Good**

Wellbeing goal:	**A Wales of cohesive communities**
Co-benefits:	Limited evidence of co- benefits relating to this wellbeing. Strongest evidence of indirect benefits from the creation of new local employment.
Quality of evidence:	**Mixed**

Wellbeing goal:	**A Wales of vibrant culture and thriving Welsh language**
Co-benefits:	Limited, indirect evidence of co-benefits relating to this wellbeing goal. Strongest evidence relates to local job creation and attractive communities to retain people living in Welsh towns and villages.
Quality of evidence:	**Weak**

Wellbeing goal:	**A globally responsible Wales**
Co-benefits:	Good evidence of the health benefits associated with reduced air pollution and of contributing to Sustainable Development Goals in Wales. The evidence on indirect contributions to biodiversity and environmental quality outside Wales is weaker.
Quality of evidence:	**Good**

Barriers, levers and dependencies

The key **barriers** to achieving co-benefits from housing decarbonisation are:

- The lack of enough people with the specialist skills and capacity to deliver housing retrofits at scale.
- The difficulty in scaling up certain approaches, including behavioural change and delivery models which involve community organisations, which are aimed at achieving health and community benefits and capturing economic benefits for local people.
- Motivating private landlords to invest in improvements to private rented properties (through lack of financial incentives, wider market factors, lack of equity, and cultural and behavioural factors).

In addition there are a range of barriers affecting delivery of large scale housing retrofit programmes. These include regressive financing mechanisms, control of capital costs, poor quality implementation, disruption to residents and concerns about payback period.

The **levers** available and **dependencies** to achieve or maximise co-benefits are:

- MEES regulations, Rent Smart Wales and the Housing Health and Safety Rating System (HHSRS). These were identified from wider evidence but not considered sufficient to fully address barriers to decarbonisation in the private rented sector.
- A whole-house approach to retrofit and safe retrofit procedures were identified as ways to maximise health and equity benefits.

- Smart meter rollout, market reforms (including to support fairness) in the energy sectors were identified as levers to motivate and reward consume participation in domestic demand reduction.

- Targeting can help maximise strongly felt health benefits by a smaller number of people whereas wider-scale programmes can enable health benefits at population scale. A balance of targeted and more general rollout programmes is likely to achieve a fair balance.

- Government procurement policies to require use of local supply chains and creation of local jobs, training and apprenticeships can maximise local economic benefits. A direct government approach may favour realisation of co-benefits by making use of local government knowledge of housing stock and local communities.

A number of **timeline considerations** were identified:

- Large scale energy efficiency housing retrofits are likely to be most able to proceed in a timely fashion, assuming available capital and revenue funding. This is because key economic, health and social co-benefits from the delivery of such programmes are well understood. However, there will be a time-lag before certain co-benefits are achieved and are detectable at scale, notably physical health improvements, measurable reductions in fuel poverty rates, improved community resilience and community cohesion.

- Skills and capacity shortages in specialist retrofit are likely to impede large-scale high quality retrofit delivery at pace. Overcoming these shortages is likely to be important to build confidence amongst households to participate in programmes.

- Heat decarbonisation and domestic demand response technologies are still at trial or demonstrator stages; wide-scale rollout will not happen until these technologies and the supporting business models are better developed.

- Low existing rates of smart meter rollout and of domestic low carbon generation installation in Wales may disadvantage households in terms of accessing newer demand reduction opportunities.

Key evidence gaps

The key **gaps in the evidence** on co-benefits which merit further research are:

- Longer term evidence of co-benefits, including for health, community resilience, fuel poverty and equity, community cohesion and cultural heritage. Longitudinal or retrospective approaches and qualitative data collection methods are likely to be appropriate.

- Empirical evidence of co-benefits associated with novel and non-mainstream approaches to heat decarbonisation and electricity decarbonisation, including low carbon heat networks, heat pumps, heat-as-a-service and domestic demand side response services (eg variable tariffs).

- The extent to which those co-benefits which are reported to result from targeted and smaller-scale domestic retrofit programmes can be replicated in larger-scale schemes or schemes which target different tenure and dwelling types.

- The value and effectiveness of behavioural change interventions in enabling the achievement of co-benefits at scale and over time.

- Empirical (non-modelled) evidence on lasting job creation, net employment effects and distributional employment effects.

- Local environmental and biodiversity benefits from circular economy approach to retrofit and housing quality improvements.

- The effectiveness of retrofit interventions as a way to futureproof homes against risks of overheating due to climate change.

- Whether improvements to the energy efficiency of homes feed through to improved school attendance and educational attainment.

- The effect of housing retrofit programmes or housing-related renewable energy projects on intangible 'felt' community and cultural benefits, using qualitative research approaches.

Next steps

On the basis of current evidence identified by this REA, economic, health, resilience and equality (mainly fuel poverty) co-benefits provide the strongest basis to support the carbon reduction based arguments for investment in housing decarbonisation. Better evidence on educational and community cohesion benefits would help add to the case, as would evidence to show the lasting nature of benefits.

This evidence review has identified valuable insights regarding levers, dependencies and barriers to achievement of co-benefits. Policy and programme developers should pay attention to these insights, many of which come from evaluations of affordable warmth programmes in Wales and England.

An important area for attention concerns the design and effective employment of policy and other levers to motivate retrofit activity in the private rental sector, particularly to support investment in improving 'hard to heat' properties.

The newer areas of heat decarbonisation and demand flexibility will require ongoing attention to understand and shape their contribution to co-benefits as well as decarbonisation. The Welsh Government's Smart Living programme and the Cardiff University-led Flexis programme are examples of ongoing work in Wales to better understand these areas of activity and so build the evidence base on co-benefits.

1 Introduction

1.1 Background

Wales has committed to drastically reducing its carbon emissions under the Climate Change Act (2008). The Welsh Government has gone further by being the first country to declare a climate emergency, accepting the Committee on Climate Change's recommendation to reduce Wales' emissions by 95% by 2050 and setting out an ambition to reach net zero emissions by 2050[1].

Wales has some of the oldest and least efficient housing in the UK and Europe: housing is responsible for 21% of Wales's greenhouse gas emissions (Green et al. 2018). The Decarbonisation of Homes in Wales Advisory Group's (2019) report: Better Homes, Better Wales, Better World recommended that the Welsh Government should set ambitious targets to achieve net zero emissions from Welsh homes by 2050, and that political parties make a strategic commitment to decarbonising homes (Decarbonisation of Homes in Wales Advisory Group, 2019). Welsh Assembly Members have welcomed the report and its recommendations, recognising the vast scale of the challenge and large investment required[2]. In responding to the report, The Minister for Housing and Local Government recognised the opportunity to achieve wider benefits from investment in housing retrofit:

"Energy retrofitting our homes is not just a major opportunity to significantly reduce our carbon emissions and meet our targets, but also to tackle fuel poverty, improve comfort and quality in homes, create jobs and promote training, supply chains and industries in Welsh communities. It is about making Wales prosperous, green and equal."[3]

Prosperity for All: the national strategy sets out a national ambition to create a more equal, green and prosperous Wales (Welsh Government, 2017). Decarbonisation now features as the sixth priority in Prosperity for All (Welsh Government, 2019a). The Wellbeing of Future Generations Act (2015) requires all Welsh public bodies to work towards seven long term wellbeing goals that consider the needs of future generations (Welsh Government, 2015).

The number of households living in fuel poverty in Wales has decreased from 332,000 households in 2008 to 155,000 in 2018. This is a decrease of 14 percentage points from 26% in 2008 to 12% in 2018 (BRE / Welsh Government, 2019). Reductions in fuel poverty over this time are due to a 37% fall in modelled energy consumption and an average 25% increase in incomes, outweighing the 47% rise in average unit fuel price. The percentage of households living in fuel poverty in 2018 in the social housing sector was 9%; in the owner occupied sector was 11%; and in the private rented sector was 20%. This would suggest that programmes to drive improvements in the energy efficiency of social

[1] Wales accepts Committee on Climate Change 95% emissions reduction target https://gov.wales/wales-accepts-committee-climate-change-95-emissions-reduction-target

[2] Statement by the Minister for Housing and Local Government: The Independent Review on Decarbonising Welsh Homes Lines 416 – 425 https://record.assembly.wales/Plenary/5844?lang=en-GB#A53270

[3] Statement by the Minister for Housing and Local Government: The Independent Review on Decarbonising Welsh Homes Line 425 https://record.assembly.wales/Plenary/5844#A53270

housing, notably the Welsh Housing Quality Standard (WHQS), have contributed to the significantly lower rates of fuel poverty in this tenure type, particularly as compared to the private rented sector.

Increasingly, there is recognition that decarbonisation programmes can generate valuable co-benefits - additional social, economic, health and environmental benefits, including fuel poverty alleviation (Mayne, 2018; Green et al. 2018). In the context of the large scale investment required to decarbonise Welsh homes, this report presents evidence of the co-benefits of housing decarbonisation and highlights existing gaps in the evidence. The findings from this review will contribute to the evidence base, which in turn will inform the Welsh Government's policy position on housing decarbonisation.

1.2 Research questions

This study sought to answer the following primary research questions and to construct an evidence-based value case for decarbonising homes in Wales:

1) What are the specific wider benefits (or co-benefits) of decarbonising homes which are relevant to Wales in relation to the Wellbeing Act and Prosperity for All goals and objectives?
2) How does the available evidence base apply to the housing stock and is it applicable to all housing or just certain archetypes?
3) What is the strength, quality and robustness of evidence to support the case for each wider benefit identified?
4) What are the gaps or research limitations in the current evidence base?

The research also sought to address the following secondary questions:

5) What are the key levers to achieving wider benefits?
6) What dependencies influence the achievement of wider benefits?
7) What are the potential barriers to the achievement of wider benefits of decarbonisation?

The following interpretive questions were considered in discussing the evidence:

8) What are the potential additional cost considerations for achieving wider benefits?
9) What is the likelihood of being able to achieve the wider benefits?
10) What is the expected timeline over which the wider benefits could be achieved?

1.3 Summary of approach

The study used a Rapid Evidence Assessment (REA) method to address the research questions. The REA involved a methodical and documented search for evidence, data extraction, and consideration of identified studies against a pre-determined set of exclusion and inclusion criteria. Those studies selected for inclusion were then analysed in detail to identify evidence responding to the research questions[4]. A REA is a quicker, less exhaustive version of a systematic review. The scope of the REA

[4] https://www.gov.uk/government/collections/rapid-evidence-assessments

was broadly set, encompassing evidence for achievement of social, economic, health and environmental co-benefits resulting from interventions of differing type and scale (see Table 5).

This REA identified 61 good quality studies with relevant evidence on the co-benefits of decarbonising homes. These were included for more in-depth analysis. For each of the studies included, sections of relevant text were coded in nVivo software to codes for: types of co-benefit; dependencies and levers for achieving benefits; barriers to achieving co-benefits; associated costs; and quality of evidence. Coding was checked and, in some cases, added to by a second researcher. The complete sets of coding were then interrogated against the research question to which the coding related. Where necessary, reference was made back to longer relevant sections within the document itself to gain more contextual information. In certain cases, particularly for findings reported in literature reviews, references were traced further back to verify the accuracy of how primary research findings had been presented in the documents under review.

The reporting of findings on co-benefits is by chapters relating to Welsh Government wellbeing goals to which the co-benefits could contribute. Each chapter includes reporting of levers, dependencies and barriers to co-benefits and an assessment of the quality of evidence. The report identifies key evidence gaps meriting further research. The REA does not fully exhaust all available evidence but rather provides an overview of the density and quality of evidence for different types of co-benefits to support decision-making. As such, subsequent more in-depth reviews might result in revisiting of some of the reported conclusions.

1.4 Key terms

'Decarbonising homes' refers to interventions that result in reduced demand-side carbon emissions from existing housing, including for heating and other energy-usage within the home. A long list of 'scoped in' interventions was identified, including retrofit measures to improve the energy performance of existing homes, more efficient or low carbon heating, behaviour change support and low carbon electricity generation, both domestic and grid-wide. It excluded measures for new build housing and measures involving electric vehicles.

The term 'co-benefits' is used throughout this report as a concise direct replacement for the term 'specific wider benefits' used in the research questions. Co-benefits (or specific wider benefits) are the added public benefits achieved as a result of housing decarbonisation actions. The focus on co-benefits brings attention to the fact that investment in housing decarbonisation can not only contribute to the achievement of carbon emission targets but can also bring about benefits for health and wellbeing, job creation and economic growth, reduced fuel poverty, improved resilience and local environmental benefits (Jones et al 2019).

1.5 Scope

The REA focused on studies from the UK and the Republic of Ireland but also considered evidence from other OECD countries, with consideration of their comparability in terms of weather, housing stock, and governance. The search focused on studies published since 2014, extended back to 2004 where insufficient more recent evidence was identified.

The study primarily examined evidence relating to housing-focused interventions which aimed to achieve energy efficiency improvements and carbon emission reductions, though many interventions also or mainly prioritised fuel poverty reduction or health benefit goals. The scale of interventions reviewed ranged from UK-wide modelled interventions and large scale area-based programmes in Wales (notably the Arbed 1 & 2 schemes and the Nest scheme) down to community schemes with fewer than ten households involved. Whilst some programmes were area-based, others were targeted at specific household types, notably low income households and/ or those with specific cold-related health conditions

The most commonly referenced interventions were domestic energy efficiency and/or heating retrofit programmes that provide a range of home energy efficiency measures including insulation, draught proofing, double glazing, improved efficiency boilers and heating systems, or low carbon heating systems or controls. Some programmes also included draught proofing, domestic energy advice promoting behaviour change around energy use, tariff switching and income maximisation. Some schemes delivered wider activities including training programmes and community benefit schemes. Other interventions included in the review were behavioural change projects that delivered energy advice and smart technology; domestic energy efficiency standards and small scale renewable energy installations.

The REA did not identify any suitable studies which reported findings on the co-benefits from the Wales Housing Quality Standard (WHQS) programme. The most recent Welsh Government statistical release shows that over 98% of all social housing dwellings had achieved compliance with the requirement for an energy rating (SAP ≥65) by March 2019. The overall standard requires dwellings to meet a range of standards, including that the dwelling be adequately heated, fuel efficient and well-insulated. The lack of documented evidence on the co-benefits of this large-scale housing improvement programme in Wales is a key gap in the evidence base.

The study focused on findings regarding the co-benefits of housing decarbonisation rather than on findings of the carbon emission reductions achieved. Whilst many, but not all, of the studies related to interventions intended to achieve carbon emission reductions, many of the reports from empirical studies did not report achieved or estimated carbon reductions.

The range of co-benefits considered was shaped by the seven wellbeing goals in the *Wellbeing of Future Generations Act* (2015), as shown in Table 1.

Table 1: Types of co-benefits considered in this REA

Wellbeing Goal	Types of possible co-benefits considered
Globally responsible	Carbon emission reductions, global air pollution, benefits for future generations, environmental benefits outside Wales
Prosperous Wales	Low carbon economy, skills and training, increased economic activity, decent jobs, tax revenues and savings to public purse and to NHS, local jobs, reduced benefit payments, Welsh supply chain, lower fuel bills, fuel poverty reduction, reduced investment in future network costs
Resilient Wales	Neighbourhood improvement, regeneration of public housing estates, local environmental benefits, energy security and resilience, healthy local

	economy, future-proof housing, improved security of homes, resilience of electric grid
A More Equal Wales	Good quality housing for all, reducing fuel poverty, equal educational opportunities and outcomes, social equity, health equality
A Healthier Wales	Healthier society, reduced health inequalities, improved quality of homes, improved mental health, improved physical health, reduced death rates, improved wellbeing, reduced social isolation, improved air quality
A Wales of More Cohesive Communities	Community engagement and leadership, neighbourhood improvements, improved community cohesion.
A Wales of Vibrant Culture and Language	Vibrant local economy to attract and retain Welsh people, pride in local community, increased community involvement.

1.6 Description of search, data extraction and analysis phases

Evidence was found through a systematic search in Google Scholar search engine, through requesting evidence from Centre for Sustainable Energy (CSE)'s professional network and through the Welsh Government's Decarbonisation Library. A systematic search was conducted using a set of search terms in Google Scholar search engine. The search terms were developed to identify evidence of co-benefits resulting from efforts to decarbonise homes that contribute to the Wellbeing Goals. Researchers scanned the first 30 papers identified by each search term, and selected papers based on the following exclusion criteria that considered the relevance of the paper. This assessment was based on the titles of documents (see Appendix A for details of the search terms used and exclusion criteria). The total number of papers included at this stage was 811 (see Table 2).

Exclusion Criteria

- Does not directly address one or more research questions
- Solely focused on carbon benefits, not co-benefits/wider benefits
- Pre-2014, include 2004-2014 where evidence is thinner
- Evident it does not meet quality standards

Table 2: Numbers of papers initially identified

Source	Papers (before removing duplicates)
Systematic search (Google Scholar)	573
Welsh Governments Decarbonisation library	220
CSE professional network	18
Total	**811**

Papers saved to a Mendeley database after passing the above criteria were then assessed against the inclusion criteria (see Table 3). This was assessed through reading the abstract, executive summary and additionally, in some cases, the introduction and methodology sections of papers.

Table 3: Inclusion criteria

Study type	Inclusion criteria
Quantitative	Large or medium sample size to enable good estimate of mean or small sample size with procedures to account for skew
Quantitative modelling	At least 20 cases/variable modelled; randomised selection procedures; well-reasoned theoretical model.
Quantitative comparative	Random control test or non-random control test with good comparability of groups
Qualitative	Appropriate data collection methods; procedures for data collection & analysis; reflective re bias; credible interpretation.
Theoretical paper	Only considered for inclusion where covers types of co-benefits poorly covered by other forms of evidence. Well-reasoned and referenced, credible approach for interpreting empirical information.
Literature review	Clear and well-reasoned method for selection of evidence included, some consideration to quality; relevant focus of review.

Duplicate papers were removed. In total 61 papers were identified that were relevant and contained robust evidence. 28 were judged as high quality, meeting and exceeding the above criteria and 33 were judged to be of medium quality, meeting the above criteria. Low quality papers did not meet the above criteria or were found, on more detailed examination, to have limited relevance to answering the primary research questions.

The 61 papers scoped in were then reviewed in more detail. Nvivo software was used to extract and categorise evidence. Researchers assessed the areas of evidence to identify where evidence was strong and where there were evidence gaps. The strength of evidence is discussed alongside the findings in later sections. This includes mention within the text of where evidence appears to be more theoretical or based on assertions and therefore less robust than evidence well-grounded in empirical evidence.

1.7 Types of studies included

A range of studies were included in this assessment, consisting mainly of:

- Evidence reviews, including systematic reviews that present co-benefits of decarbonising homes and energy efficiency.
- Project evaluations or studies examining specific projects.
- Economic modelling studies;
- More theoretical papers were only used for those areas with limited available empirical evidence of co-benefits.

1.8 Report structure

This report is structured around the seven Wellbeing Goals set out in the Wellbeing of Future Generations Act (2015) to present the evidence of co-benefits of housing decarbonisation.

- Chapter 2 outlines the evidence for 'Contributing to a prosperous Wales'
- Chapter 3 outlines the evidence for 'Contributing to a resilient Wales'
- Chapter 4 outlines the evidence for 'Contributing to a more equal Wales'
- Chapter 5 outlines the evidence for 'Contributing to a healthier Wales'
- Chapter 6 outlines the evidence for 'Contributing to a Wales of cohesive communities'
- Chapter 7 outlines the evidence for 'Contributing to a Wales of vibrant culture and language'
- Chapter 8 outlines the evidence for 'Contributing to a globally responsible Wales'
- Chapter 9 presents Conclusions and Implications

Each 'Contributing to' chapter is headed by a boxed summary of key findings and the quality of the evidence. Each chapter presents evidence on co-benefits, levers and dependencies for achievement of specific co-benefits, consideration of the quality of the evidence and of gaps in the evidence base.

2 Contributing to a prosperous Wales

Key findings

- There is strong evidence of the economic benefits of investing in decarbonising homes including boosting GDP, creating jobs, saving money on energy bills, savings to the public purse and reducing fuel poverty. Evidence is drawn from robust programme evaluations and well-designed economic modelling studies.
- Energy efficiency and renewable energy are increasingly important contributors to the global, national and local economies. Modelling studies indicate that large-scale investment in energy efficiency can boost GDP. Results predict that for each euro invested the economy grows by between €0.9 and €3.70.
- Domestic energy efficiency programmes in Wales, notably the Arbed and Nest schemes, have delivered benefits to the local and national economy.
- A key form of economic benefit is via job creation, with estimates that investment in energy efficiency and renewable energy can generate around 19 jobs over per million pounds invested lasting the lifetime of the power generation plant. Arbed was found to generate numerous local jobs in Wales. The Welsh Government's requirement for use of local contractors helped boosted the positive effect on local employment, with multiplier effects for local economies.
- For each energy efficiency job, it is estimated that 0.4 to 4.8 indirect jobs are supported.
- Energy efficiency and renewable energy generates two to four times more jobs than fossil fuel equivalents. On average, fossil fuels generate 0.15 jobs per Gigawatt hour (GWh)[5], renewable technologies generate 0.65 jobs per GWh and energy efficiency generates 0.8 jobs per GWh.
- Energy efficiency investment can generate tax revenue and savings for the Welsh Treasury and offers good value for money, including through savings to the NHS. It is estimated that every £1 invested in a national programme could generate £1.25 in tax revenues.
- Cold homes are estimated to cost the NHS £2.5 billion per year. Energy efficiency measures and advice can significantly reduce householders' use of health services.
- Energy efficiency retrofit and renewable energy generation can generate training opportunities. Local impact requirements on scheme managers can boost this impact.
- Domestic energy programmes make an important contribution to reducing rates of fuel poverty, through reductions in fuel bills. However, it is hard to generate accurate estimates of the actual reduction achieved.
- The achievement of reduced fuel bills can leave households with more disposable income for other spending, though real life fuel bill savings tend to be less than those predicted in modelling studies. In interventions aimed at fuel poor and low income households who previously under-heated their home, taking some of the savings as improved comfort/warmth is a desirable trade-off benefitting household well-being at the expense of economic benefits.
- Trials of various opportunities for domestic participation in new flexible, low carbon opportunities including solar PV, storage and demand side response, suggest these can help reduce household energy bills as well as achieving as-yet limited system benefits.

[5] Gigawatt hours, abbreviated as GWh, is a unit of energy representing one billion (1 000 000 000) watt hours and is equivalent to one million kilowatt hours. Gigawatt hours are typically used as a measure of the output of large electricity power stations.

2.1 Low carbon economy

Energy efficiency and renewable energy are increasingly valuable to the global, national and local economies. The UK's green economy has grown at approximately 5% per year over the last 10 years, this is much higher than overall annual GDP growth of between 1.5% and 3.1% (Jones et al. 2019). In 2017, the low carbon and renewable energy economy grew by 6.8%, and was valued at nearly £45 billion by the beginning of 2018 (ibid).

Modelling studies predict that a large scale investment in energy efficiency would boost GDP (Jones at al. 2019; Cambridge Econometrics, 2015; Hartwig et al. 2017). Metrics used to measure the economic value of energy efficiency investment are variable and challenging to compare (Campbell et al. 2014). One metric used describes the change in GDP per unit invested. One systematic review reported a range of estimates between 0.91 and 3.73 for the change in GDP per unit of investment. This means that for each Euro invested in an energy efficiency programme, GDP can be expected to grow by between €0.91 and €3.73 (Campbell et al., 2014). Some studies predict economic impacts using econometric and computable general equilibrium (CGE) models that combine economic theory with economic data to predict the impact of interventions on the economy, taking into account the knock-on effects and interactions between different sectors of the economy. Such studies predict that delivering energy demand reductions of 8% and 5% (respectively) in 2010 through energy efficiency, would create GDP growth of 1.3% and 0.1% to 0.2% (respectively) (Campbell, 2014). Washan et al. (2014) estimate that an UK-wide £40 billion energy efficiency programme could deliver £3.20 benefit for every £1 spent, and generate a 0.6% relative improvement to GDP. Jones et al. (2019) more modestly suggest that investing in large scale energy efficiency programme could boost UK GDP by 0.25% to 1.1%.

Cambridge Econometrics (2015) identified that investing in energy efficiency has positive impacts on GDP. They model the impact on EU wide energy efficiency investment and find that the most ambitious energy efficiency scenarios could have the greatest, but most uncertain impact on GDP. Less ambitious scenarios had modest impacts on GDP to 2030 (between -0.2% and 1.3%), their most ambitious energy efficiency scenario predicts the larger impact on GDP (-1.2% to 4.4%). However, they highlight that there are important question marks around the economy's capacity to deliver the investment needed to achieve these impacts.

Domestic energy efficiency programmes in Wales have achieved positive effects on the local and national economy. The Welsh Government's Warm Homes Nest scheme leveraged £1.6 million ECO funding to Wales. It achieved a local multiplier effect of £2 – meaning for every £1 spent it generated £2 of local economic benefit (Nest, 2018). Arbed 2 achieved a local multiplier effect of £2 in South Wales and £1.90 in North Wales (Warren and Griffiths, 2017). Overall investment in the Welsh and UK economy resulting from Arbed 2 was calculated to be over £100 million (Warren and Griffiths, 2017). The Warm Homes Oldham programme aimed to lift 1,000 people out of fuel poverty by delivering energy advice and measures to vulnerable households in South Yorkshire and was found to have contributed £178,000 to GDP as a result of increased employment (£340 per household) and £37,700 due to reduced sickness absences (£72 per household) (Bashir et al. 2016).

2.2 Tax and Savings to Treasury

Energy efficiency investment provides value for money, tax revenue and savings for the Treasury. Frontier Economics' (2015) analysis of government impact assessments concludes that investing in an energy efficiency programme could provide better or comparable value for money than other major schemes, including the smart meter rollout and HS2 (this analysis predates recent escalations in the predicted costs of both of these schemes).[6][7] This analysis does not include some of the main social benefits of an energy efficiency programme, including health improvements and savings to the NHS, so is likely to underestimate the value for money.

Washan et al. (2017) found that a national energy efficiency programme could generate £1.25 in tax revenue for every £1 invested, generating £50 billion in tax revenues from a £40 billion investment, equating to 'high' value for money for an infrastructure programme.

Arbed 2 was calculated to have generated £300,000 in savings to treasury (Warren and Griffiths, 2017). Warm Homes Oldham evaluation calculated that the programme led to fiscal savings of £137,300 due to reduced benefit claims (£262 per household) (Bashir et al. 2016).

Cold homes have been estimated to cost the NHS £2.5billion/year (BRE 2010, in Ige et al 2019).The Warm Homes Oldham scheme generated considerable NHS savings through energy efficiency measures and advice. Analysis of NHS savings for mental health found the measures resulted in NHS savings of £45,000 per year, or £51 per adult without included physical health benefits (Bashir et al 2016). This study was based on household surveys before and after the programme. An evaluation of a council-led programme aimed at the private rented sector in Liverpool estimated that, through the removal of excess cold hazards (identified as a risk to suboptimal home temperatures), the programme could save the NHS and wider society £42 million over a 10 year period. (NICE 2016, in Jones et al 2019). Other studies find statistically significant reductions in the use of health services following the installation of energy efficiency measures (Howden-Chapman, 2007; Bray et al. 2017; Mayne 2018). More evidence for financial savings from reduced use of health services is presented in 2: Contributing to a prosperous Wales.

2.3 Decent jobs

Over 200,000 people in the UK currently work in the low carbon economy, with many more working in the supply chain, and it is estimated this will grow to two million by 2030 (Jones et al. 2019). These jobs appeal to young people: a recent BEIS survey found that 65% of 18-24 years olds are interested in working in the green economy (BEIS 2018 in Jones et al. 2019).

Multiple studies report that investing in energy efficiency generates jobs, but quantified estimates of how many jobs vary. Campbell's (2014) review finds a range of estimates of jobs created per one million euro investment in energy efficiency of between 7 and 22, or between 0.76 and 19.61 jobs per kilotonne of oil equivalent (ktoe) saving. Rosenow et al (2014) point to Janssen and Staniaszek's

[6] https://www.parliament.uk/business/committees/committees-a-z/commons-select/business-energy-industrial-strategy/news-parliament-2017/rollout-smart-meters-chair-comments-17-19/

[7] https://www.gov.uk/government/speeches/hs2-update-3-september-2019

(2012) review of over 20 sources that concluded that, for every one million pounds spend on energy efficiency, 19 jobs are supported. Pridmore et al.'s (2017) literature review suggest that for every million euros invested in energy efficiency, between 9.2 and 11.7 jobs are generated.

The metrics used to measure job creation, along with timescales considered and assumptions vary between different studies. Blyth et al's (2014) review of low carbon job creation estimates found stronger evidence for energy efficiency and renewable energy creating jobs in the short term, including in times of recession or post-recession. The review considers a 'job' as full time equivalent job lasting the lifetime of the power generation plant. However evidence of longer term job creation was weaker and more mixed. Blyth et al suggest that in the longer term, requiring more labour is a less appropriate metric of economic benefit as it implies lower output per worker (ibid.). In their comparative analysis Blyth et al take one job to be one full time equivalent role for the duration of the power generation plant lifetime, so jobs during the construction and manufacturing phase are spread across the power generation plant lifetime (ibid.)

Jobs created differ between technology, and most estimates do not consider indirect jobs created by investments. Rosenow et al (2014) assume that an estimate of 19 created per one million pound investment would apply for solid wall insulation, although this is likely to be conservative as the installation is very labour intensive. They point to a wide range of estimates of the indirect jobs created by investing in housing repair and maintenance and construction, between 0.4 and 4.8 indirect job per each direct job. They use 1:3 as an approximate mid-point ratio of direct to indirect jobs supported.

There is substantial evidence that suggests investing in renewable energy or energy efficiency generates more jobs than investing in fossil fuels. Rosenow et al. (2014) points to studies that show investing in energy efficiency generates between two times and four times as many jobs as investing in fossil fuels. Blyth et al.'s (2014) review indicates that renewable energy and energy efficiency sectors generate more employment than coal or gas power generation. The average of the estimates they reviewed suggests fossil fuels generate 0.15 jobs per GWh, renewable technologies generate 0.65 jobs per GWh and energy efficiency generates 0.8 jobs per GWh. From a one million pound investment, this equates to 6 jobs from fossil fuels, 16 from renewable energy and 14 from energy efficiency. However there are large variations in estimates and relatively few data points (Blyth et al. 2014).

Whilst job gains are expected to be larger than losses, the move to a low carbon economy will lead to some job losses, particularly in fossil fuel industries. There have been calls for government action to ensure communities that suffer job losses are able to benefit from new jobs (Jones et al. 2019).

2.4 Local jobs through Welsh supply chains

Studies estimate a national energy efficiency programme could generate local employment. Washan et al. (2014) calculate that a UK-wide energy efficiency investment programme to improve the housing stock to EPC C would increase employment by over 100,000 net jobs over 10 years.

The £58 million investment in energy efficiency measures and advice though Nest between 2011 and 2014 supported 46 SMEs, creating a total of 83 apprenticeships and jobs (Marrin et al. 2015). Some installers also reported the income safeguarded jobs that were under threat (ibid.)

The potential for a local supply chain of technology and services can lead to job creation and multiplier effects for the local economy (Mayne, 2018). Arbed 1 was found to generate numerous jobs in Wales through using local contractors. Four of seven manufacturers were based in Wales, and 16 of 20 contractors and sub-contractors were based in South Wales (Patterson, 2016). The total revenue to Welsh business resulting from Arbed 2 is calculated to be over £26 million (Warren and Griffiths, 2017). In South Wales, 323 new jobs were created at Melin Homes, 100 of which took people out of unemployment. 198 more were saved from redundancy (Warren and Griffiths, 2017). Householders appreciated the service being delivered by local people and the visible community benefits. In North Wales, 175 permanent jobs were created at Willmott Dixon, and 766 apprenticeship weeks provided. The total income to people living in Wales as a result of the Arbed 2 scheme is estimated to be over £26 million (Warren and Griffiths, 2017).The Welsh Government required that the tendering of installation work and materials for the Arbed 2 scheme be undertaken separately. This proved successful in enabling involvement of more SMEs who would not have had the cash flow to purchase the materials to bid for work as part of the scheme (Warren and Griffiths, 2017). Designing programmes to overcome such barriers for local supply chains and promoting local businesses can help boost the local economy.

2.5 Skills and training

Energy efficiency retrofit and renewable energy generation can generate skills and training opportunities (Jones et al. 2019). The Nest scheme manager is encouraged to use Welsh SMEs and ensure training opportunities and apprenticeships are created. Between 2011 and 2018, the scheme delivered 8,422 apprenticeship weeks (Nest, 2018). In 2017/18 the Nest team completed training to become STEM ambassadors and now work with schools and young people to increase awareness of employment and career opportunities (ibid).

Arbed schemes had targets for weeks of training provided. Arbed 1 delivered 1,704 training weeks, exceeding its training target. Training opportunities included carpentry, plumbing and heating, electrical, construction skills and plastering (Patterson, 2016). In South Wales, Arbed 2 delivered 716 accredited training weeks, 34 apprenticeships, and 37 graduate placements. In North Wales, Arbed 2 delivered 766 apprenticeship weeks (Warren and Griffiths, 2017).

FILT Warm Home Service provided training to housing investment agency staff on providing energy advice and protecting the health and wellbeing of vulnerable clients. One of the identified benefits of the scheme was the acquisition of new skills, knowledge and improved motivation for staff receiving training (Bashir et al. 2013).

The review identified many other examples of training delivered through local energy efficiency and renewable programmes. The RetrofitWorks cooperative aims to expand the market for energy efficient retrofit and support local installers in three pilot areas in the South of England. They have modelled the opportunity for new jobs and predict over 7,000 jobs could be created in each of their pilot areas by the end of the four year programme, and nearly 2,000 sustained beyond this (Jones et al. 2019). Repowering London delivers community-based renewable energy projects in deprived London councils. They deliver a youth training programme for 16-25 year olds that covers a range of skills and knowledge for the renewables sector (Jones et al. 2019). However, the effectiveness of these schemes has not yet been evaluated.

Evidence for training opportunities generated by energy efficiency and renewable energy schemes is greatest where the scheme explicitly aims to generate training opportunities. Government action to ensure funded schemes provide appropriate training opportunities can help deliver sustainable local labour markets (Jones et al. 2019).

2.6 Lower fuel bills

Modelling studies show that a national energy efficiency programme will reduce fuel bills. Washan et al. (2014) model the fuel bill savings from a national energy efficiency programme to improve homes to EPC C through funded measures for low income households and loans for able-to-pay households. They estimate annual savings for able to pay households to be £416, and £203 after loan repayments, and £408 for low income households, equating to £245 after comfort taking where householders increase the temperature or duration of their heating regime following the installation of measures. This equates to a net benefit of £4.95 billion after comfort taking and loan repayments. Actual fuel bill reductions are considerably higher for households in the able to pay group as they are less likely to be under-heating their homes before the intervention. Lower income households are likely to see lower actual reductions in bills, but improved levels of comfort and reduced levels of worry about fuel bills.

Sovacool (2015) indicates that £1 invested in UK Warm Front programme produced up to £36.30 in benefits over a 20-year period. These benefits include monetised energy savings and resulting reductions in household costs but not health benefits (referenced in Pridmore et al. 2017).

The evaluation of Warm Homes Oldham estimated large fuel bill savings as a result of the programme, averaging 5% of households' income (Bashir et al. 2016). The median combined savings from physical works, Warm Home Discount and behaviour change was £678. £256 of this was from physical works. This was based on predicted bills but acknowledges the actual savings may be smaller due to comfort taking from households under-heating before the intervention (ibid).

Arbed 1 estimated average household savings would be £216 per year if heating behaviour did not change but acknowledged some householders would take comfort gains over financial savings (Patterson. 2016). The greatest energy bill savings were calculated for a 1980s flat that received ASHP with a saving of over 50% (ibid). The combined potential financial savings for all households involved in the Warm Wales Programme is £285,000 per year. The investment involved in the Warm Wales Programme of £9,658,509 equates to a payback period of 33 years across the whole the programme.

The Nest programme generated an estimated average annual saving to benefitting households to be £507, totalling £7.48m, equating to a payback period of 7.75 years based on the £58 million investment (Marrin et al. 2015). 61% reported their household bills had reduced as a result of installed measures. Other financial benefits to householders include over £1.5 million in annual benefits claimed by those receiving benefit checks and £57,000 received through the Warm Home Discount (ibid.).

Nest home energy efficiency improvements are reported to have delivered estimated energy bills savings of £408 per household per year (Nest, 2018). This is also based on assumed energy use not

considering behaviour change. These were targeted at inefficient homes, and most measures were central heating installations.

Where schemes providing energy efficiency measures and advice attempt to measure actual financial savings after the intervention, they tend to be lower than modelled but still considerable. The difference is generally explained by householders heating their homes to a warmer temperature after the intervention. An evaluation survey conducted after Islington Council installed external wall insulation on over 250 homes showed the median monthly winter bill reduced by £10, and considerably less households reported limiting heating due to concerns about the cost (Jones et al. 2019).

Results for the Warm Front Scheme evaluation survey contradicted this, and residents reported finding it easier to manage their fuel bills after the intervention (Green and Gilbertson, 2008). Conversely Green and Gilbertson's (2008) analysis of the Warm Front Scheme found that fuel consumption actually rose after the intervention. The reasons for the increase were unclear but may be partly caused by missing areas of insulation, increased ventilation by opening more windows (as homes are warmer) and participants not understanding how to use new heating systems efficiently. Other studies have found many households do not understand how to use their heating system efficiently (Pridmore et al. 2017).

Participants taking part in innovation projects trialling energy storage, demand side response and small scale renewable generation benefited from reduced bills. Projects have trialled different methods of engaging householders and promoting energy saving behaviours. Behaviour change is very complex, people's behaviours are influenced by a great number of factors and change over time, so promoting change is challenging (Pridmore et al. 2017). Providing incentives, including financial incentives through reduced energy bills, is an important way to share the system benefits of demand side response (ibid). 60% of customers taking part in time-of-use tariff trials as part of the Consumer Led Network Revolution innovation project reduced their energy bills, as did many in other innovation projects trialling domestic PV with batteries (SE2, 2015). Other projects encouraging behaviour change through ICT based feedback on energy use generated fuel bill savings (Renz and Vogt, 2015). Such projects require effective engagement to achieve behaviour change, as noted by Mayne (2018).

Local renewable energy generation has also reduced fuel bills for households and organisations that have installed generation, most commonly solar PV. If installed in 2016, a typical 4kWp installation could save a household £60 per year on their fuel bills, along with earning £200-255 in Feed-in Tariffs (FiTs) (Mayne, 2018). However, as the FiT has been funded through fuel bill levies, it has increased fuel bills for most households. Whilst this has generated a range of benefits, the costs has been disproportionately paid by low-income households who are unable to afford the upfront costs of solar PV (ibid).

2.7 Fuel poverty

Many domestic energy programmes have generated substantial reductions in fuel poverty, under-heating and stress and anxiety caused by fuel bills. A household is regarded as being in fuel poverty if they are unable to keep their home warm at reasonable cost. In Wales, this is measured as any household that would have to spend more than 10% of their income on maintaining a satisfactory

heating regime. Any household having to spend more than 20% is defined as being in severe fuel poverty. A different definition, the low income high costs (LIHC) definition, is used in England (several of the interventions forming the focus of studies reviewed in this study were in England). This is, where a household's fuel costs are above the median, and, were they to spend that amount, they would be left with a residual income below the official poverty line (BEIS, 2019). In practice, it can be hard to ascertain the contribution of an intervention towards reducing rates of fuel poverty (Campbell, 2014; Pridmore et al. 2017). Contributing factors to fuel poverty are household energy requirements, fuel prices and household income (BEIS 2019). Where projects reduce the household energy requirements or increase the income of low income households, this can be expected to make a longer term contribution as they address the causes of high household energy requirements and provide long term options to reduce household expenditure on fuel for heating (Pridmore et al. 2017).

The Warm Homes Oldham evaluation estimated that the programme took 75% of participating households out of fuel poverty. However, this estimate relied on assumptions about the extent to which households followed energy advice (Bashir et al. 2016). The evaluation found that after the intervention there were statistically significant increases in participants' self-reported ability to keep their homes warm in cold weather and reductions in self-reported practices of under-heating. The project targeted low income households at risk of fuel poverty who also met health vulnerability criteria (ibid).

A council-led intervention to install external wall insulation on 269 hard to treat social housing properties in London led to a sizeable reduction (from 73% to 20%) in the proportion of households who self-reported limiting how much they heated their homes due to concern about the costs (Jones et al. 2019). This was associated with findings of a £10 decrease in the median monthly bill amount over winter from before the insulation was installed to the final survey, from £70 to £60. (ibid).

The highest rates of fuel poverty are experienced by households in the private rental sector, where homes are least efficient (BEIS, 2019). The private rental sector faces the challenge of a reduced incentive for domestic energy efficiency investment in rental homes as the cost is borne by the landlord and the benefit largely enjoyed by the tenant (Pridmore et al. 2017; Ambrose, 2015). Recently introduced Minimum Energy Efficiency Standards (MEES) require newly leased properties to achieve EPC Band E or above, with a further aim to improve the stock so that most of the private rented sector has a rating of EPC Band C by 2030. The current and future impact of these standards on energy efficiency and fuel poverty in the private rental sector is as yet unclear (BEIS, 2019).

2.8 Demand side response and grid cost savings

The increasing integration of renewable energy sources into the grid, along with electrification of heat, will contribute to achieving housing decarbonisation. Demand-side response (DSR) services are an instrument for managing network constraints and to optimise use of networks: these services are likely to become more important in a future decarbonised grid.[8] Effective use of DSR can reduce the need for costly reinforcement of the electricity grid and so can generate large costs savings, which

[8] Energy Networks Association (2019) Demand Side Services
http://www.energynetworks.org/electricity/engineering/demand-side-services.html

ultimately benefits electricity bill payers (Qadrdan et al. 2017). Domestic DSR uses financial incentives (e.g. via variable tariffs) to reward consumers for lowering or shifting their electricity use away from times of peak demand (ibid). Domestic opportunities for DSR include modified running time of smart refrigerators, off-peak use and modified cycle time of washing machines and shifts in the timing of water heating (ibid). Qadrdan et al. (2017) quote a previous study that estimated the theoretical flexible domestic demand at the peak time of a winter day in 2030 to be 26%. Bradley et al. (2013) compare studies around the costs and benefits of demand response and find a reasonable economic case. More recently, Qadrdan et al. (2017) modelled the cost savings from UK-wide DSR and estimated costs savings to GB power system to be around £60 billion between 2010 and 2050. They highlight that the actual impact will be dependent on levels of engagement (ibid). These are uncertain, particularly in the domestic sector, since incentives to participate in demand side response will need to outweigh inconvenience. It is also likely that some households will face barriers to their ability to participate in DSR (Crisp & Kruja, 2019).

2.9 Quality of evidence

The evidence presented in this chapter draws on high quality modelling studies. It is important to note that many of the studies include non-domestic and domestic energy efficiency when discussing economic impacts and do not report separately on the impacts of each sector. The metrics used to measure economic impact are inconsistent and often not comparable. Modelling studies have high uncertainty as they are dependent on multiple factors which can change over time, notably including future energy prices (Campbell, 2014).

Domestic fuel bills saving estimates are subject to many uncertainties, particularly around householders' actual heating behaviours and changes in behaviours following interventions. Comfort taking is accounted for in studies, where households choose to heat their home to a warmer temperature or for longer periods of the day following an intervention rather than taking all of the potential savings in their energy spend following energy efficiency improvements (Washan et al. 2014). Modelled or estimated savings can incorrectly predict householders' behaviour. Much of the evidence around fuel bill savings following domestic energy schemes is reliant on householder recall of their bill: this may be inaccurate and unreliable, as actual bill amounts can take a long time to reflect reduced energy use. A variety of other factors, including seasonal changes in external temperature and changes in household circumstances can also affect heating needs (Green and Gilbertson, 2008; Bashir et al. 2013). Householders may be unable to detect changes in bills and direct debit amounts may not reflect actual energy consumption (Gilbertson et al. 2006; Green and Gilbertson, 2008). Some savings in bills may be associated with switching to a cheaper deal rather than by actual reductions in energy consumption (Green and Gilbertson, 2008).

2.10 Gaps or research limitations

The research has identified a lack of non-modelled evidence on the job creation and other economic benefits of national scale interventions, whether for integrated housing decarbonisation programmes or for national energy efficiency programmes. There are also gaps in understanding of the employment impacts of shifts in jobs between sectors, leaving net job gains and regional distributions uncertain.

Innovation trials testing new technologies are small scale and localised and can use technologies that are not yet commercially available and household engagement models that are unlikely to be scalable. There is a gap in systematic reviews of the findings from such trials to assess what type and scale of co-benefits are likely to be achievable under 'real life conditions'.

3 Contributing to a resilient Wales

Key findings

- This chapter draws on evidence which consider neighbourhood improvement, environmental benefits, energy security, household economic resilience, future-proofing homes and home security, mainly from area-based housing energy efficiency schemes. There is strong evidence that decarbonising homes interventions can promote economic resilience and energy security. Evidence for household and environmental resilience benefits highlights dependencies on the quality and approach to delivery, whilst there is weaker evidence on more intangible benefits of increased community resilience.
- Area-wide retrofit schemes can help strengthen communities and social capital. Local job creation, additional community engagement activity and in-kind contributions towards improving community assets are valued community benefits of such schemes.
- Investment in domestic energy efficiency can reduce fuel poverty, increasing resilience to changing energy prices and increasing disposable income for households.
- Insulation and draught-proofing, done well, can reduce risks of overheating in summer, increasing resilience to future, more frequent heatwaves.
- External wall insulation can improve resilience to likely increases in excess rainfall and associated damage. Again, this must be done well to avoid risk of harm.
- Use of sustainable building materials for structural and insulation improvements to existing buildings can bring wider environmental benefits from sustainable forestry and woodland management and by avoiding damage from demolition or from use of high carbon materials.
- Demand reduction in the domestic sector can make an important contribution to the reliability of the grid.
- Domestic renewables and demand reduction can reduce future reliance on non-OECD sources of fossil fuels, increasing Wales' energy security.
- Local decentralised renewable generation and domestic technologies can also build household and community resilience in Wales' future energy system. The evidence in this area needs strengthening.
- Research gaps include a better understanding of the opportunities for those living in existing homes, including low income households, to benefit from new opportunities as part of future energy system.

3.1 Strong communities & confident citizens

A retrofitting scheme targeted at communities with high rates of fuel poverty was reported to make the area more attractive, build confidence that the area is worth investing in and build pride and care in the community – as found for the Arbed Warm Wales Programmes (Patterson, 2016; Power, 2008; Warren & Griffiths, 2017). The Arbed 2 scheme evaluation noted that the local job opportunities created by the scheme were highly valued as a contribution to the community. The Arbed 2 evaluation also found that the schemes, by providing a common focus for residents, helped to revive neighbourly interaction (Warren & Griffiths, 2017).

Community benefits were reported to be additionally strengthened through community engagement activities, including with local schools, community groups, improvements to community assets, as well as through the in-kind contributions of labour to install or improve community assets, such as a solar PV system and repairs to community buildings (Warren & Griffiths, 2017).

3.2 Healthy economy

Investment in domestic energy efficiency can make a significant positive impact on the resilience of low income households to changing energy prices, enabling them to reduce their total spend on energy and so reduce their household costs, thereby increasing disposable income (Pridmore et al 2017; Ribeiro *et al.*, 2015;). Sovacool (2015, as reported in Pridmore 2017) reports £1 investment in UK Warm Front programme produced up to £36.30 in benefits over a 20-year period. Nest home energy efficiency improvements are reported to have delivered estimated energy bills savings of £408 per household per year (Nest 2017) and Arbed 1 scheme is reported to achieve £216 per household per year (Patterson 2016). Modelling by Washan et al 2014 showed that their proposals for national infrastructure investment to improve the energy efficiency of UK housing would achieve £8.61 billion per annum in total energy bill savings across housing stock, after comfort taking (accounting for energy price inflation) and would reduce by £60 (to £160 per home) the modelled increase in energy bills that would be experienced by homes in 2030 from a 50% gas price spike (Washan et al 2014). Further evidence of the economic benefits of decarbonising homes is presented in Chapter 2: Contributing to a prosperous Wales.

3.3 Green Wales - resilience to effects of climate change

Several reports make the case that cost effective investment in domestic energy efficiency and decarbonisation of the power sector can achieve increased resilience to the effects of climate change (Jones et al 2019; Ribeiro et al 2015). Insulation and draught-proofing enable warmth in winter and reduce risks of overheating in summer, improving resilience in the face of increased risks of heatwaves (Liddell and Morris, 2010 in Pridmore et al 2017; Jones et al, 2019).

However, studies also highlighted that where poor design leads to overheating, this could risk reduced resilience (Shrubsole 2014). External wall insulation to increase air tightness can also make properties more watertight, increasing resilience to likely increases in excess rainfall and associated risks of water damage and mould (ibid). Poor design and a lack of ventilation were also identified as factors which could result in worsened internal air quality (ibid).

3.4 Local environmental benefits

The use of forestry, woodland and agricultural products as sustainable building materials for structural and insulation measures in domestic building energy efficiency improvements can avoid environmental damage from the extraction, processing and manufacture of high carbon building materials and can also support wider environmental benefits from sustainable management of forestry and woodland, with biodiversity and recreation benefits (Pridmore et al 2017). Refurbishment of existing homes can avoid the environmental harm associated with demolition of existing buildings (Pridmore et al 2017).

As well as enabling energy demand reduction, green roofs and green walls can bring benefits for reduced urban heat island effects, management of surface water run-off, improved external air quality, absorption of CO_2, habitat creation and enhanced biodiversity benefits (Bianchini and Hewage, 2012, Castleton et al, 2010; Rosenzweig et al., 2016; quoted in Pridmore et al 2017). These are all impacts valued for consideration in Treasury Green Book Supplementary Guidance on valuation of energy use and greenhouse gas (BEIS, 2018).

3.5 Future energy security and resilience to transitions in the energy system

A secure and resilient energy system is defined in the Treasury Green Book Supplementary Guidance as:

"one in which supply and demand can balance at prices which are not excessively volatile. That is, physical interruptions to supply (which result in excess demand) and price spikes do not occur".

Actions to reduce residential energy demand and increase domestic renewables will contribute towards reduced future reliance on fossil fuels from non-OECD countries, benefitting future energy security (Pridmore et al 2017; Glynn et al., 2017). Domestic demand reduction also contributes to increasing the reliability of the electricity grid (Ribeiro et al; DECC & Ofgem 2011a&b, referenced in BEIS 2018) which will become increasingly important as the energy system transitions to greater reliance on intermittent sources of energy. Research from the USA reports that more efficient homes that maintain temperatures offer resilience for households in case of power outages (Ribeiro et al 2015). Growth of local, decentralised energy schemes involving community-owned renewable generation are also identified as means to improve the UK's energy security and reduce the likelihood of future energy shocks (Jones et al. 2019). The refurbishment of existing homes to be able to accommodate new technologies, such as electric vehicles and heat pumps, as part of our future energy system, will increase their resilience to a changing energy system, though the options may be more costly and more limited than for new homes (Jones et al 2019; Ribeiro et al 2015). This can also enhance the future opportunities for households to participate in demand side response as a means to contribute to the future resilience of the energy system, through flexible demand from space and water heating and appliances such as fridges and washing machines (Qadrdan et al 2017).

3.6 Quality of evidence

This chapter draws on the latest Green Book supplementary guidance regarding energy security, peer-reviewed articles reporting on well-designed modelling studies, and a number of evaluation and literature reports for national governments. Two reports are of more questionable quality. Ribeiro et al. (2015) draws on published journal articles to support its arguments but is not based on primary research and has likely risk of bias, as it is published by the American Council for an Energy-Efficient Economy. Washan et al. (2014) clearly sets out its modelling methodology but has likely bias, as it is sponsored by industry bodies. Although it reports UK-wide impacts, it uses England-only data and so findings may be less relevant to Wales, which has a high proportion of off-gas homes. The toolkit by Jones et al. (2019) is supported by an independent literature review but it may be selective in using findings which support its case for local authorities to invest in sustainability actions. Certain, more innovative opportunities, such as demand side response, have had limited uptake within the domestic sector. This means that the assumptions used in modelling studies may not be realistic and so the findings need to be viewed with some scepticism.

3.7 Gaps or research limitations

The evidence on community benefits, including benefits to the local economy, is heavily reliant on the findings from evaluation of the Arbed schemes, which were targeted at communities with area deprivation and fuel poverty. There is not such strong data of community resilience benefits from schemes with a less targeted approach. The evaluation used a before and after approach that provides a snapshot of benefits shortly after the completion of the work. This means there is a limitation in understanding the longer term community resilience impacts. The wider debate on the relative benefits of demolition or refurbishment is contested, but includes recognition that renewal is less disruptive to residents and has positive social effects. Few articles fitting the search criteria of this review addressed the effects on community resilience of other types of housing interventions (see e.g. Power 2008). It is likely that further evidence would be identified with a different search criteria.

The changing energy system will bring opportunities and risks for households, and new ways to strengthen resilience, including through new services such as demand side response and associated technologies, such as smart appliances, batteries and heat pumps. Recently published research by Citizens Advice explores some of the barriers to participation. More work is needed to understand what this means for communities and households in Wales.

More intangible community benefits (e.g. community engagement and resilience) are not well documented in the evidence reviewed. Such benefits are more likely to be reported in internal reports or small-scale qualitative evaluations of smaller-scale schemes, including those funded or delivered by the charitable, voluntary or community energy sectors. As such, there is a paucity of compelling evidence on how intangible community benefits can be delivered at scale and what are the levers and dependencies that enable these to be achieved through larger scale programmes.

4 Contributing to A more equal Wales

Key findings

- There is strong evidence from evaluation and real-life experimental trials to show that retrofit programmes promote economic equality, reduce fuel poverty, and tackle health inequalities, especially when targeted towards low income households and areas with high relative rates of multiple deprivation. There is a paucity of evidence to show that targeted interventions result in improved educational outcomes for children in cold homes.
- Fuel poverty, as an important form of social and economic inequality, has been a focal area for evidence on energy efficiency programmes, with good understanding of the harm caused by living in a cold home. Evidence of the effectiveness of solutions is good, though because of the complexity of the issues, there remain evidence gaps.
- Energy efficiency measures can reduce expenditure on fuel, reducing fuel poverty, increasing thermal comfort and increasing low income households' ability to redirect disposable income to other essentials, including food and clothing, and enjoy a socially acceptable lifestyle.
- Poor quality housing is a widespread problem in Wales, as elsewhere in the UK. Home energy efficiency programmes can make homes warm up quicker and stay warm longer, increasing health and comfort, and improving the quality and value for homeowners. An important factor influencing the extent of benefits is the approach to improvements as single or multiple measures or a whole house approach.
- Targeted energy efficiency improvements can reduce health inequities associated with a cold home, benefiting low income households, children, older people, disabled people and other socially disadvantaged groups.
- Poorly heated homes can be harmful to children's education, increasing risks of missing school and making it harder for children to do homework. Better heating and insulation can reduce the number of missed school days by children with asthma and may contribute to improved educational attainment, though the evidence on this is weak.
- In light of Wales' ageing housing stock, construction worker training and skills are crucial to achieve improved housing quality and avoid damage which creates maintenance and repair issues.
- Homeowners need reassurance of the risks and benefits of participating in schemes or undertaking their own improvements.
- Newer low carbon innovations, such as domestic demand side response services, which require households to have the financial and technical means to participate and which can disrupt household routines may give rise to inequitable outcomes. Such innovations, over time, risk creating new forms of energy injustices, with some households 'left behind'. Care is needed to design approach that do not unfairly exclude or harm lower income or other potentially vulnerable households.

4.1 Good quality homes for all

Poor quality housing, with problems of draughts, damp, mould and overheating are widespread problems across UK housing stock. But many households put up with these problems rather than find the money and endure the hassle and disruption of dealing with them (Lipson 2017, in Sovacool et al 2019). Home energy efficiency programmes bring direct benefits to the quality of homes across

different tenures, with associated health and comfort levels for residents and increased house values for homeowners (Butterworth et al, 2011 in Mayne 2018; DECC 2013 in Sovacool et al 2019). Well-insulated homes warm up quicker, stay warm longer and can be less prone to damp. The extent of benefits can vary according to what measures are installed, from one-off measures such as insulation, double-glazing, new boiler and/or heating systems to more costly whole house retrofits.

Wales has a high proportion of older hard-to-heat and hard-to-treat homes, with 35% of the stock built before 1919, where there were no construction standards in terms of thermal performance (Green et al 2018). Roof insulation is present in over 90% of dwellings but to very varying degrees. Wall insulation is present in two-thirds of cavity wall homes, but many retrofits are now having this removed due to health and performance concerns (ibid). Less than a third of solid wall dwellings have wall insulation. Domestic renewables installations are scarce, with social housing leading the way in uptake (ibid).

In their evaluation of the Arbed 1 scheme, Patterson et al (2016) argue for the increasing importance of good quality, well designed and executed retrofits in the context of an ageing building stock. From their review of previous retrofit programmes, they observe that this will need a systematic improvement in construction worker training and skills to achieve improved housing quality and avoid detrimental impacts to the home. The Arbed 1 Warm Wales retrofit programme sought to reduce fuel poverty in strategic regeneration areas, with over half of properties improved being owned by local authorities, a quarter owned by housing associations and 20% owner occupied. Patterson et al note that it required additional time to reassure and support householders in the private sector to engage in the programme to undertake improvements). The average SAP rating achieved following works was 69. The evaluation underlined the importance of not just installing low carbon measures but also rectifying any damage that will reduce the benefit of the investments. This is important not only to achieve carbon reductions but also to improve the quality of the housing. Likewise Wade et al 2016 (in Sovacool et al 2019) reported instances where bad practice in installation of new heating system caused damage affecting the interests of homeowners who chose to invest in low carbon improvements. The evaluation of the Arbed 1 scheme generated recommendations for large scale retrofit programmes to minimise disruption to residents, keep costs down and support long term maintenance of housing (Patterson et al 2016). The findings by Wade et al would point to the need for similar attention to improve practice in small scale schemes and the able-to-pay market.

4.2 Fuel poverty

Domestic energy programmes have generated substantial reductions in fuel poverty, under-heating and stress and anxiety caused by fuel bills (Jones et al. 2019; Bashir et al. 2016). Where programmes reduce domestic fuel bills, this will lead to reductions in fuel poverty that disproportionately benefit fuel poor, low income households (Pridmore et al. 2017; Jones, 2019). Where projects reduce the fuel costs or increase the income of low income households it can be expected they will reduce fuel poverty. Home energy efficiency improvements provide a long term solution to fuel poverty as they address the causes of high fuel costs and provide long term options to reduce energy costs (Pridmore et al. 2017). Schemes that target low income households have a greater impact on reducing fuel poverty and improving health, as households heat their home to a warmer (and

healthier) temperature following the intervention. More evidence for fuel poverty reduction benefits is presented in Chapter 2 Contributing to a prosperous Wales.

4.3 Equal educational opportunities

There is evidence that children living in poorly heated homes are more than twice as likely to suffer from asthma and bronchitis as children living in warm homes (Jones et al 2019). A number of other studies also report that living in a cold home can be harmful to educational opportunities, by making it harder for children to do homework in a cold room or in a crowded single heated room (and by inference, negatively affecting educational achievement) (Campbell 2014) or through ill-health affecting school attendance levels (Harker 2006; Howden-Chapman 2007; Ige et al 2019; Jones et al 2019), with the inference that this would affect attainment levels. Robinson (2015), in a small scale pilot study, found that children living in homes at greater risk of fuel poverty had lower mathematics attainment at school entry.

A study from New Zealand found that the installation of more effective heating in insulated homes of households with children with diagnosed asthma resulted in improved indoor temperatures, lower levels of asthma symptoms, with on average 21% fewer days of absence from school after the intervention. After allowing for other factors (Howden-Chapman et al 2011, in London School of Hygiene and Tropical Medicine (LSHTM) 2015) Somerville et al (2000), referenced in Harker (2006), reported that installation of central heating into damp, unheated bedrooms was associated with a reduction in school days missed due to ill health: prior to installation children lost 9.3 days per 100 school days because of asthma and 1 day per 100 school days afterwards.

The delivery of housing decarbonisation programmes also offers a direct route for increasing equal educational opportunities for young people. An example of this is the Repowering programme, which, through its accredited youth training programme, has upskilled 16-19 year olds in deprived areas of London with technical skills training in solar panel making, industry-specific visits and transferable co-operative business, marketing and community engagement skills (Jones et al 2019). Young people who complete the course are awarded certificates and receive careers advice to boost confidence and employability.

4.4 Social equity

Investment in energy efficient fabric improvements is particularly important for low income households in terms of benefits for their disposable income and for their health, achieving social equity benefits (Campbell 2014; Pridmore et al 2017). The Marmot review found that the level of energy efficiency affects how low income households spend disposable income on food and clothing (Marmot review team 2015). Studies on the effect of energy efficiency interventions targeted at low income households report more marked beneficial effects for health than interventions with non-targeted interventions (Maidment et al 2014). As discussed in section 2.6, occupants of previously under-heated homes may choose to heat their home more adequately, taking some or all the financial savings as increased thermal comfort. (Pridmore et al 2017). Targeting low income homes is likely to generate greater health benefits but lower fuel bill reductions. Demand response opportunities, particularly peak pricing as a means of encouraging lower use of electricity at peak times, raises concerns about inequitable outcomes, with the potential of disrupting family mealtimes of low-income households, with potentially harmful knock-on effects to the positive contribution

made by family mealtimes to nutrition, literacy development, emotional wellbeing, improved academic achievement and decreased likelihood of drug and alcohol abuse (various refs, in Murtagh et al 2014). Demand response potentially adds to the burden of parents and carers, notably working parents who have compressed time options for completing caring and housework responsibilities (Murtagh et al. 2014).

Low carbon technologies, including solar panels, new heating systems, external wall insulation, batteries and smart appliances require significant upfront capital investment, which can be a barrier to participation for low income households. However the low running costs mean that they can contribute to tackling fuel poverty, with upfront investment by a public body, such as a national programme, local authority or housing association (Pridmore et al 2017). New business models may favour home owners and more 'attractive' customers over low income and vulnerable customers. Sovacool et al (2019) highlight that factors such as lack of access to fast broadband or a smartphone, being a tenant, lack of access to capital, or living in low value housing could make households more at risk of not being able to participate in future low carbon opportunities, even though they pay to subsidize them, creating a new form of energy injustice (Sovacool et al 2019).

4.5 Health equality

The NICE guidelines point to certain groups as being more at risk from cold homes than the general population. These groups overlap with groups that are low income and at risk from ill-health. Evidence for health benefits resulting from energy efficiency and advice for these groups is mixed, with the strongest evidence around older people and people with respiratory problems (Grey et al. 2017; Jones et al. 2019).

Grey et al (2017) highlights that interventions that target low income households and households with existing health conditions have greatest health benefits for participating households. However, they may not reduce health inequalities at a population based scale due to the often small proportions of the population supported (Grey et al. 2017). More evidence of the impacts on health inequalities is presented in Chapter 6 Contributing to A healthier Wales.

4.6 Quality of evidence

This chapter draws on a range of high quality sources of evidence, including well-designed experimental evaluation of interventions, well-structured literature reviews and a peer-reviewed theoretical journal article. The strongest evidence on educational equality is from New Zealand. The UK evidence on direct benefits for equal educational opportunities for young people is weak, drawing on descriptive information prepared by the Ashden award recipient (the judging process involves a site visit, but this is unlikely to involve detailed verification of impacts).

4.7 Gaps or research limitations

There is a lack of at scale findings on the effect of (decarbonised) warmer housing interventions on educational attainment of children at different points in their education, or of the effects of training schemes associated with the delivery of decarbonisation on educational outcomes for young people. There is a lack of empirical evidence on the actual social justice effects associated with emerging low carbon technologies and associated consumer offers to households, including demand side response

and peak pricing as well as domestic PV and new heating services, as highlighted by Sovacool et al (2019). The effectiveness of different measures for improving the delivery of large scale retrofit schemes, such as those recommended in the Arbed 1 evaluation, also require testing to understand what difference they make – and the costs associated with them.

5 Contributing to A healthier Wales

Key findings

- There is a strong body of evidence that fuel poverty is harmful to physical and mental health through the direct effect of low temperatures in the home and the stress of high fuel bills. Cold homes are estimated to cost the NHS £2.5 billion a year.
- There is also an increasingly substantive body of evidence that energy efficiency programmes result in improved mental health and wellbeing and contribute to reducing health inequalities.
- There is good evidence of the health benefits of energy efficiency measures for people with existing respiratory conditions.
- Understanding of the savings to the NHS and social care costs from investment in energy efficiency programmes remains reliant on modelled findings, due to the complexity and cost of designing suitable robust empirical studies in tandem with investment and delivery of such schemes. There is some evidence to suggest that interventions can reduce the frequency of doctors' appointments and hospital visits by people with existing health conditions.
- Improved energy efficiency with adequate ventilation reduces the risk of cold homes and damp and mould; this reduces associated health risks.
- Poor design, and inadequate ventilation can increase over-heating and reduced indoor air quality.
- There is strong evidence that health-focused energy efficiency interventions, many of which are targeted at low income households, benefit mental health through:
    - Reducing stress and anxiety caused by high fuel bills and debt.
    - Reduced anxiety associated with the reliability of heating and water.
    - Improved mobility.
- Evidence of the benefits to physical health of energy efficiency interventions is less certain. Self-reported measures of physical health have been shown to improve after interventions, and there is evidence of reduced GP visits following energy efficiency measures. However some studies find no statistically significant impact.
- There is some evidence of wellbeing benefits from improved home energy efficiency and advice including:
    - Reduced social isolation where householders are willing to socialise in their homes, reduced school absenteeism from illness.
    - Improved productivity at work.
    - Improved nutrition where householders have higher disposable income to spend on food.

5.1 Introduction

The importance of housing energy efficiency measures to improved health is recognised both nationally and internationally. The Paris Agreement (UNFCCC 2015) recognises the right to health and requires the protection of disabled people and people in vulnerable situations. A WHO COP24 special report on health and climate change (2018 highlights how mitigation, including in energy and housing, can contribute to reducing disease and illness from indoor and outdoor air pollution. It recommends actions to reduce both carbon emissions and air pollution. In the UK, the NICE guideline on excess winter deaths and illness and the health risks associated with cold homes (2015) recommends housing insulation and heating improvement programmes and grants and other

actions to improve the quality of housing as part of a preventative health and wellbeing-led strategy. NICE expects to publish a guideline on indoor air quality in December 2019.

5.2 Healthier society

The evidence reviewed references and adds to a body of established evidence that fuel poverty, poor quality, damp and cold homes negatively impact physical and mental health in adults and children (amongst others, Bashir et al 2016; Grey et al 2017; Ige et al 2019; Marmot review 2015; Mayne 2018;), as reflected in the NICE guidelines (2015) and its supporting evidence base (Public Health England et al 2014; LSTHM 2014; LSTHM 2015). The pathways through which harm is caused are summarised succinctly as a result of the direct consequences of low indoor temperatures and more indirectly, through financial stress, social isolation, restricted warm living space and 'heat or eat' dilemmas (Grey et al 2017).

Several evaluation reports focused on the effectiveness of national and local retrofit and advice schemes to address cold home hazards and tackle fuel poverty across different tenure types, including the Warm Homes Healthy People Fund (Bashir et al 2016), the Warm Front Scheme (Gilbertson et al 2006), the Warm Homes Nest scheme (Nest 2018); Northern Ireland Warm Homes Scheme (Rosenow et al 2014), the Arbed schemes (Grey et al 2017; Warren and Griffiths, 2017). In addition, multiple systematic reviews (eg Ige et al 2019; LSTHM 2015; Liddell & Guiney 2015; Maidment et al 2014) of empirical, mainly quantitative studies found evidence to support the importance of good energy efficiency and adequate ventilation to contribute to improved health and wellbeing.

A high quality empirical evaluation of the area-wide Arbed scheme in Wales found no significant improvements in objectively measured physical or mental health outcomes within the study period, but did find quantitative evidence that the intervention led to improved subjective well-being and improved psychosocial outcomes that may be part of pathways to better health. These included increased thermal satisfaction, fewer reported financial difficulties, increased satisfaction among participants with the repair of their homes, fewer reported housing-related problems and more social interactions (Poortinga et al 2018).

5.3 Improving the quality of homes

Multiple evidence sources reviewed concluded that schemes that involved the installation of insulation and heating measures and provision of supporting advice contributed to safer and more efficient homes, reducing hazards of cold, damp and associated mould in the worst quality housing, which reduce the health risks associated with cold homes (Bashir et al 2016; Ige et al 2019; LSHTM 2015).

There was consistent evidence that affordable warmth programmes resulted in increased indoor temperatures and/or increased warmth or thermal comfort and improved ability to keep the home comfortably warm in cold weather (Bashir et al 2016; Campbell 2014; Gilbertson et al 2006; Grey et al 2017). Studies variously emphasised the importance of a whole building approach to energy efficiency (Thomson et al 2013), insulation (Campbell 2014), insulation and central heating systems (Gilbertson, Grimsley & Green 2012 in Campbell 2014), ventilation and central heating (Ige et al 2019) as contributing to improved health.

The evidence also includes findings that insulation, heating & integrating ventilation as part of retrofit measures result in reduced damp and association mould build-up, with a beneficial effect for indoor air quality (Campbell 2014, Grey et al 2017). A modelling study of retrofit scenarios to meet 2030 carbon reduction targets found that proper implementation of fabric and ventilation resulted in net positive effects on morbidity and mortality, demonstrating the importance of strong regulation and compliance with regulations (Hamilton et al 2015).

The review found little evidence from empirical studies of housing decarbonisation interventions preventing overheating – this was also the finding of Pridmore et al (2017) in their review for the Scottish Government. Overheating was raised in a limited number of studies as a problem of existing housing (Sovacool et al 2019) and new buildings (Pridmore et al 2017), where a combination of design issues, heat retention and occupant behaviour have raised health concerns which can particularly affect vulnerable groups. Shrubsole (2014) reported that recent work raised the risk of poor design or lack of climate adaptation leading to summertime overheating, making buildings uninhabitable. She pointed out that overheating in airtight buildings can also be associated with an increase in indoor air pollution whilst other design solutions, such as a more flexible approach to design, increased thermal mass and providing reflective roofs may be more suitable. The option of increased air conditioning would undermine decarbonisation objectives of increased insulation. She argued that a more holistic, multi-disciplinary approach to housing policy is needed. There appears to be a gap in evidence regarding overheating in existing buildings and the effect of housing decarbonisation measures as a cause or solution to overheating.

5.4 Improved mental health benefits

The evidence includes strong findings of the association between poor mental health and fuel poverty, with a key cause of stress attributed to coping with high energy bills and debt (Campbell 2014; Mayne 2018). Raised temperatures and thermal comfort were also associated with better mental health (Gilbertson et al 2006; Bashir et al 2016), including by helping individuals gain improved mobility and to enjoy improved emotional wellbeing (Green & Gilbertson 2008).

In turn, there is strong evidence that affordable warmth interventions, many of which were in schemes targeted at low income households, led to improved happiness and mental health, overcoming financial stress of coping with high energy bills and preventing anxiety and borderline depression (Bashir et al 2016; Green & Gilbertson 2008; Liddell & Guiney 2014 in Campbell 2014). Reduced anxiety was also found to result from having a reliable, controllable source of heat and hot water (Gilbertson et al 2006). However, the evaluation of the Arbed 1 scheme found no statistically significant impact on objective measures of mental health (Grey et al 2017).

Stockton et al. (2018) found improvements in self-reported mental health amongst households who received large and small measures through the Health Innovation Fund. 35% reported their mental health improved following installation of measures (ibid). Householders were also asked a number of questions about their wellbeing including relaxation, confidence and cheerfulness before and after the intervention. Participants reported improvements across all measures with the largest improvement seen in relaxation (ibid).

Interventions targeted at low-income households may result in comfort-taking, with people who were previously under-heating their homes now heating to higher temperatures or for longer

periods of time. Thus some health and wellbeing benefits may be at the cost of more sizeable carbon reductions (Campbell, 2014). However, one study found that comfort was reported to be achieved by low income households at lower temperatures than those recommended by government with positive implications for climate change targets (Green & Gilbertson 2008).

Liddell & Guiney 2015 report on a longitudinal regeneration study in Glasgow which found that mental health was independently associated with improvements to both the home (including the external appearance of the home, the front door and insulation) and to the residential neighbourhood. They conclude that improving energy efficiency in people's homes as part of a wider neighbourhood renewal can maximise benefits for mental health.

5.5 Improved physical health

The literature includes findings of self-reported improvements in physical health, reduced GP visits following interventions including energy efficiency measures and advice (Bashir 2016; Mayne 2018; Watson et al. 2019; Stockton et al. 2018). Studies which used more demanding objective measures found no statistically significant impact on physical health status e.g. for the Wales Arbed 1 scheme (Grey et al 2017; Poortinga et al 2018).

5.6 Reduced winter deaths

The NICE guidelines bring attention to the importance of reducing the effects of cold homes on excess winter deaths (2015). People living in the least efficient quarter of homes are a fifth more likely to die during the winter than people living in the warmest homes (Watson et al. 2019). In 2017/18 Wales had the highest Excess Winter Death index across England and Wales (ibid). However the supporting evidence study (LSHTM 2015) found that evidence on housing related interventions did not generally measure mortality rates, due to issues of timeframe and sample size requirements. Other evidence did report benefits for reduced winter deaths (Peralta et al 2016; Mayne 2018). There appears to be a gap in the evidence of home energy efficiency improvements reducing excess winter deaths.

5.7 Improved respiratory health

There is limited, mixed evidence on the impacts of housing interventions for respiratory health, including asthma and COPD. The evidence review by LSTHM found limited evidence of the positive benefits of housing interventions for asthma and COPD (LSHTM 2015) and found that specific types of housing interventions in the homes of children with asthma may be justified on the basis of their health benefits alone (LSHTM 2015). A small study in Cornwall found days taken off school by asthmatic children fell after installing central heating in the 59 damp properties (Watson et al. 2019). Households receiving measures through Nest made less GP visits for respiratory conditions, a 3.9% drop was seen across the intervention group (of 16,5353 recipients) compared to a 9.8% increase for a control group (of 24,895) (ibid). An evaluation of the Arbed 1 scheme found no statistically significant impact on respiratory symptoms (Grey et al 2017; also Poortinga et al 2018). This difference in findings is likely to be partly explained by the targeting strategies of Nest and Arbed, as Nest targeted vulnerable householders and Arbed targeted areas containing low income households (Watson et al. 2019).

5.8 Improved well-being

Reflecting the evidence on improvements for mental health, both reviews and evaluations found statistically significant evidence of widespread increased general well-being of residents based on subjective assessments, including for the Arbed 1 scheme (Bashir et al 2016; Campbell 2014; Grey et al 2017; Howden Chapman 2007; Poortinga et al 2018). Specific forms of improved wellbeing include reduced social isolation (see below), reduced school absenteeism, improved productivity at work and improved nutrition linked to financial savings on fuel bills (Mayne 2018). Benefits of increased privacy for studying and entertaining can be a benefit from being able to afford to heat more rooms in a home (Pridmore et al 2017). Some of these findings are inferred or drawn from limited qualitative evidence. Pridmore identify this as a research gap to better understand these pathways to wellbeing benefits.

5.9 Reduced social isolation

Specific forms of wellbeing benefits reported include reduced social isolation, through people being more willing to invite friends and family over to their home as guests, or having more disposable income to go out (Campbell 2014; Grey et al 2017; Marmot Review 2015). The Marmot review particularly highlights this as an important benefit for older people.

5.10 Reduced health inequalities

Grey et al 2017 report that interventions targeted at low income households and those with existing health conditions have stronger health effects than area-based interventions. They go on to observe that such schemes may not reduce existing population level health inequalities because they focus on a relatively small proportion of the population. They conclude that a combination of demand-led and more area-based schemes, as is the case with Nest and Arbed, may help ensure benefits are distributed.

There is some evidence that interventions, including insulation (Howden-Chapman et al 2007) and ventilation and central heating (Ige et al 2019) can help alleviate the symptoms of chronic conditions, including respiratory and cardio-vascular disease, arthritis and rheumatism and allergies (Mayne 2018). Gilbertson et al suggests this may be as much due to reduced anxiety as the physical effects of installation (2006).

The NICE guideline, and a recent Public Health England (PHE) resource on data sources, identify the following groups and risk factors for being more vulnerable to health problems associated with cold homes and/or having less contact with health services: young children, older people, people with pre-existing physical and mental health illnesses, disabled people, pregnant women, people on low income, people who have attended hospital due to a fall; isolated individuals; people living in the private rental sector; people who move into and out of homelessness, people with addictions, recent immigrants and asylum seekers and people who may find themselves in a transient state of fuel poverty due to changes in personal circumstances. This is informed by the systematic review by LSHTM (2015) and expert evidence. However, evidence on the beneficial impacts of interventions for people belonging to groups with these risk factors is limited, with the strongest evidence being for age and people with existing respiratory conditions.

5.11 Reduced demand on the NHS and social care

Two studies reference a BRE report that estimates the cost to the NHS of ill health from cold homes at £2.5billion/year (BRE 2010, in Ige et al 2019). The LSHTM 2015 review which informed the NICE guideline concluded that there are health benefits to be obtained from improvements in household energy efficiency but, from an economic view, if viewed solely as means of improving health these investments would (usually) not be justified. However, it found that with the inclusion of a wider range of co-benefits, they would be more likely to be worthwhile investments.

The Warm Homes Oldham scheme incorporated a package of installation of improved heating and insulation measures, energy advice and income maximisation support targeted at low income households with an existing health condition. Analysis of NHS savings for individuals with a common mental health problem found the measures resulted in NHS savings of £45,000 per year, or £51 per adult in the sample of 885 (Bashir et al 2016). This does not include improvements to physical health. The study was limited by not being able to access healthcare data to use as part of evaluation and it relied on a combination of monitoring data and before/after survey data to model the savings to the NHS .The study followed NHS and NICE guidelines for cost benefit analysis.

Bray et al (2017) reported a statistically significant 16% reduction (-£94.79) in health service use costs over 6 months following installation of new double-glazed windows to replace single-glazed windows and installation of a new energy-efficient combi-boiler in a cohort study of families living in social housing. A Randomised Control Trial (RCT) in New Zealand found that fitting insulation significantly improves people's self-reported health, visits to GPs and fewer hospital admissions for respiratory conditions (Howden-Chapman 2007).

A previous review of the literature (Mayne 2018) found evidence that housing interventions can result in savings in public health spending due to fewer visits to doctors and hospitals. An evaluation of a council-led programme aimed at the private rented sector in Liverpool estimated that, through the removal of excess cold hazards, the programme could save the NHS and wider society £42 million over a 10 year period. (NICE 2016, in Jones et al 2019). An evaluation of the Kirklees Warm Front programme calculated an overall cost benefit ratio of 0.2:1 for the whole project, with 20% of all costs recouped due to health benefits. Of this 50% were attributed to mental health benefits (Pridmore et al 2017).

By contrast, an evaluation of the Arbed 1 programme which used more rigorous, objective measures of impact found no demonstrable effects of the intervention on reducing rates of use of doctors and hospitals in the short and medium term, casting doubts on the cost-effectiveness of the programme from a health perspective. The evaluation stated that the longer term health impacts remain unclear (Poortinga et al 2018) but argued that Arbed's broader targeting at areas of relative deprivation means it is more likely to achieve beneficial longer term effects on reducing population-level health inequalities than the more Nest programmes which more narrowly target households with existing health conditions.. The same study recognises that the Nest programme generated more important health benefits for those participating households (targeted as having existing health conditions) than those achieved by the Arbed 1 programme (ibid.).

An important evidence gap relates to the effects of affordable warmth schemes for social care costs. With an aging population and people living longer with chronic and degenerative health conditions

and a desire for people to be able to continue to live independently, this is likely to become an increasingly significant factor in understanding the health economics of housing improvements.

5.12 Barriers / negative effects

The disruption, delays and inconvenience associated with large scale housing interventions 'done to' a community can cause stress which, in the short term, can undermine the benefits of improved living conditions. Some people can find it stressful to have limited choice in the changes made to their home as part of a large scale scheme (Green & Gilbertson 2008).

There is some evidence that retrofits can have a detrimental effect on health, associated with the choice of materials used and where insulation retrofits result in lower ventilation rates (Maidment et al 2014), with mixed evidence identified about the effect on indoor air quality from more air tight buildings (Shrubsole et al 2014).

5.13 Quality of evidence

This chapter draws on the largest range of sources and the highest quality evidence across the co-benefits considered. This includes a range of well-designed real-world experimental studies with large sample sizes and well-structured and transparent systematic literature reviews, as well as high quality modelling reports. There is some overlap in the primary research referenced in the various systematic reviews considered. Ige (2019) and Liddell & Guiney (2015) highlight issues with the limited number of studies with high methodological rigour. Liddell & Guiney also note problems with the use of a varied set of measures for mental health outcomes, whilst LSTHM (2015) raise concerns with the relevance of findings from high quality studies from New Zealand to a UK context. However, the overall quality of the evidence reviewed was generally higher than for other wellbeing goals.

A challenge for research on health impacts of housing interventions is that fuel poverty is inter-related with wider issues of multiple deprivation, making it hard to know if positive impacts are a result of the measures made or a result of other wider factors influencing health (Grey 2017). A common issue is the limited follow-up periods applied to many evaluation studies – several authors highlight the need for further research to consider the longer term health effects of housing interventions, but this comes with a warning that attribution becomes harder still over extended time periods (Grey et al 2017; Pridmore et al 2017).

5.14 Gaps or research limitations

Areas where further research would be beneficial include:

- Longer term large scale studies which enable better evidence on the effect of interventions on physical health, using 'objective' measures of health e.g. morbidity, mortality and enabling a better understanding of the cost-effectiveness of programmes.
- The effect of retrofit energy efficiency measures on the resilience of Welsh housing to overheating during summer heatwaves.
- Strengthened evidence on benefits for people in different vulnerable situations.
- Strengthened evidence on wellbeing benefits and pathways to these being achieved.

- Evidence on the health economic savings in terms of social care costs from affordable warmth housing interventions.

6 Contributing to a Wales of cohesive communities

Key findings

- This chapter draws mainly on evaluations of area-based regeneration schemes and evidence on the community cohesion benefits of community-led schemes. The quality of evidence is weaker than that contributing to other chapters. There is some evidence that area-based retrofit programmes deliver aesthetic and security benefits, sense of community pride and belonging and local capture of economic benefits. Community-led delivery or direct involvement of community organisations in delivery is identified as a contributor to community-level investment and capture of social and economic benefits.
- Community led energy projects can generate community income. Whilst most community energy projects to date have relied on Feed in Tariffs (FiTs), new models are emerging across the UK and Wales.
- Projects led by, or partnering with community organisations can help foster community benefits and reach hard to reach groups.
- Place-based retrofit schemes may improve the aesthetics of neighbourhoods, helping rebuild a sense of pride and satisfaction with the area.
- There is some evidence that place-based retrofit programmes can bring communities together and reduce social isolation.
- Regenerating properties may encourage wider investment in the area.
- Investing in the energy efficiency of properties generally increases the value of homes across different tenure types.
- The impact of improving energy efficiency on private rents is unclear. Many private landlords are unwilling to invest in energy efficiency without a direct increase in rents to recoup the costs.
- More efficient homes save landlords money through less void properties, repairs and rent arrears.
- Evidence suggests improving the efficiency of a home reduces mortgage risk.
- Requiring schemes to provide community benefits has ensured some of the benefits of energy programmes are shared with the wider community.

6.1 Community led projects

Two studies which focus on community-led action cite literature and case study evidence to conclude that locally-led schemes can deliver economic and social benefits and empower communities to take control over local finances and increase community resilience (Mayne, 2018; Jones et al. 2019). Community-led renewable energy generation schemes which benefit from feed-in tariff (FiT) payments have enabled community groups to reinvest surplus income into other forms of community activity for local social and environmental benefit (Mayne, 2018). However, the withdrawal of FiT funding has led the community energy sector to explore other ways to generate local benefits. Energy Local in Bethesda have been at the forefront of such innovation through a model that encourages the local community to match their energy use to times of generation by a local hydro plant, enabling them to benefit from cheap rate electricity, helping to both tackle fuel poverty and keep the income in the local Welsh economy (Jones et al. 2019).

Another case study from the same report identifies a community-led programme (Repowering) as having created new training opportunities for young people as part of the installation and operation of renewable energy generation schemes in London. The grassroots approach is reported to have

enabled sections of the population who tend not to be reached by more top-down schemes to be actively involved (Jones et al. 2019). The same report claims that community-led projects can build community cohesion by facilitating engagement between residents (Jones et al. 2019). However, there is a paucity of robust evidence to support this claim.

Projects seeking to reduce energy use can benefit from involving community based organisations to utilise local knowledge and networks to tailor the delivery to ensure its relevance to the target audience (Pridmore et al. 2017; Mayne, 2008). The use of participatory process to build community involvement, as used by some community groups, can motivate people, build shared values and may lead to behavioural change (Mayne 2018). Mayne references an example (from Gupta et al., 2015) where free energy-efficiency measures were given in return for residents taking part in learning groups, helping to build people's involvement and knowledge.

6.2 Attractive communities

Area-based retrofit schemes, particularly those involving external wall insulation, can improve the aesthetics of neighbourhoods. Arbed 1 involved external wall insulation which improved the attractiveness of buildings – with an expectation of providing a more pleasant place to live and improved local quality of life (Patterson, 2016). The scheme targeted areas with high levels of deprivation and private housing. Following the Arbed 2 programme, householders commented that the programme had improved the aesthetics of their communities and increased their sense of pride in their home (Warren and Griffiths, 2017). Liddell & Guiney's (2015) longitudinal study found that a regeneration project that provided home improvements that altered the appearance of homes, front doors and insulation had positive impacts of mental health.

There is some evidence that place-based retrofit programmes can bring communities together and reduce social isolation. Householders reported that the Arbed 2 bought the community together by reviving communication between households that were part of the scheme, although some commented there were some tensions when some householders were unable to access some measures (Warren and Griffiths, 2017). Following the Foundations Independent Living Trust (FILT) Warm Homes Service in South Yorkshire, approximately a third of surveyed residents reported that having a warmer home increased their ability to socialise and invite friends and family into their homes (Bashir et al. 2013). This could be expected to reduce social isolation within communities.

Investing in even one property can encourage wider investment in the area. Renovating properties can start a cycle of investment in an area by increasing the attractiveness of the area to investors, this can revalue unused buildings and bring some back into use (Power, 2008). Investment in areas can make them more attractive. However in some cases this can lead to rising prices displacing existing residents with more affluent incoming residents (ibid). This paper largely discusses refurbishment of homes that has an externally visible impact, so whilst this is likely to be relevant to improvements to external doors, windows or external walls, it is not certain whether the same effect would result from internal measures. However, improvements which make it easier to keep a home warm and reduce unsightly visible effects of damp and mould may also have similar effects.

Investing in the energy efficiency of a property generally increases the property value. Kirklees Warm Zone estimated that the combined value of increases in house prices across the 51,000 homes was £38.4 million, from an initial investment of £20.9 million (Mayne, 2018). Housing improvements

through the Arbed 1 scheme are expected to enhance the property value of homes receiving measures but this was not quantified (Patterson, 2016).

The impact of improving energy efficiency on private rents is unclear. High demand for rental properties in the UK currently leaves little incentive for private landlords to invest in upgrading properties, as the energy efficiency of properties has little impact on the rent they are able to charge (Ambrose, 2015). Ambrose's (2015) research with landlords found that landlords also found that private landlords were concerned that properties with Green Deal loans attached to them would be harder to let. A study modelling energy efficiency policy in Germany saw rents increase as a result of energy efficiency measures (Hartwig et al. 2017). However, a much higher proportion of householders rent their homes in Germany than Wales so this could be less applicable to Wales.

The review identified one study from the USA which found that homes with higher energy efficiency standards (and thus achieving ENERGY STAR certification) in the owner-occupier sector had one third less risk of mortgage repayment defaults than a control group and that the more efficient the home was, the lower the associated mortgage risks (Kaza et al. 2014).

More efficient homes save landlords money through less void properties, repairs and rent arrears. There is evidence that more efficient homes are empty for less time, for example a property rated EPC B is void for a 31% shorter average time than an E or F rated property (Jones et al. 2019). Social landlords with more efficient homes spend less money on repairs and managing void homes. Rent arrears are also lower on average on more efficient homes. This reduces the costs associated with chasing overdue payments including legal and court costs. (Jones et al. 2019).

Energy efficiency and renewable energy programmes help local people through community benefit schemes where they have been required (DECC, 2014: Jones et al. 2019). Arbed 2 required suppliers to deliver community benefits, suppliers supported community projects (including installing PV on community buildings), providing green electricity and an ongoing income from FiTs (Warren and Griffiths, 2017). Whilst future schemes will not be able to access FiTs, existing schemes will continue to generate income for the future. Other community benefits included access to gas grid for previously off-gas communities, work with schools, and improvements to community buildings and donations to community groups. The total value of in-kind donations through Arbed 2 was over £185,000 (ibid). Scheme managers were required to provide community benefits, as are most renewable generation schemes placed near communities (DECC, 2014). Requiring schemes to provide community benefits has ensured some of the benefits of energy programmes are shared with the wider community.

6.3 Safe communities

Nottingham City Homes evaluated the co-benefits of their Decent Home's programme that replaced single glazed windows with double glazing, replaced doors that were in a poor condition and installed energy efficiency measures in their social housing stock (Jones et al. 2016). Following the intervention, the number of burglaries fell by 42%, considerably higher than the 21% decrease of burglaries in the city as a whole (ibid.). Replacement of windows had a positive effect on tenant's perceptions of security in their own home, particularly for those where safety was a significant concern. This benefit was reported alongside reported benefits of improved warmth, reduced damp

and reduced draughts. The retrofit project formed part of a wider programme of activities to change attitudes towards homes and neighbourhood and build a local sense of positivity (ibid.).

6.4 Quality of evidence

Evidence for co-benefits contributing to cohesive communities is piecemeal and its quality less certain than the evidence identified under other chapters. Evaluations of area-based retrofit schemes have contributed to safer and more attractive communities. Community-led renewable generation schemes with a grassroots or engagement-led approach have built community cohesion. Evidence on the scalability of such approaches is lacking.

This REA identified limited evidence of the effects of housing decarbonisation programmes for building community cohesion. The main source of evidence came from evaluations of Arbed 2 (Warren and Griffiths, 2017). Evidence on the effect of other types of intervention is weak or lacking (Campbell, 2014).

6.5 Gaps or research limitations

The evidence for the effect of energy efficiency interventions on community cohesion is heavily reliant on evaluations of Arbed schemes and a limited number of community-led renewable energy generation related schemes.

The evidence reviewed was weak in its consideration of less tangible community cohesion benefits such as community spirit, pride or sense of belonging. Such benefits are more likely to be captured in qualitative evaluations of smaller-scale schemes, including those delivered by the charitable, voluntary or community energy sectors. There is poor evidence on the levers and dependencies that would enable more intangible community cohesion benefits to be delivered at scale.

7 Contributing to A Wales of vibrant culture and language

Key findings:

- This study has identified little evidence of how housing decarbonisation activities can contribute to vibrant culture or the Welsh language. Studies outside the scope of the literature (e.g. on the effects of more general housing renewal programmes) may provide transferable evidence.
- By contributing to the other Wellbeing Objectives, decarbonising homes can help facilitate a Wales of vibrant culture and language, mainly through economic benefits, including jobs, which can help attract and retain Welsh people.
- There is evidence from evaluation of the Arbed programme to suggest that area-based retrofits can improve the overall appearance of an area, helping rebuild pride in an area.

7.1 Prosperous low carbon economy attracting and retaining Welsh people

Decarbonising homes presents a less direct contribution to the vibrant culture and Welsh language than other Wellbeing Goals presented in the rest this report. However, the review identified a number of ways in which housing decarbonisation can support this goal.

The generation and retention of jobs in the energy efficiency and renewable energy generation sectors may help sustain a thriving culture: investment in energy efficiency is estimated to generate 7 to 23 jobs per million euros invested (Campbell, 2014; Rosenow et al. 2014; Pridmore et al. 2017) Jones at al. (2019) furthermore reported that young people are attracted to working in the green economy, which may encourage them to continue to live and work in Wales.

Government action may be required to ensure that Welsh communities that suffer job losses from fossil fuels and related industries benefit from new low carbon jobs (Jones et al. 2019). The Welsh Government procurement policy strongly supported use of local Welsh contractors as suppliers to the Arbed schemes as well as driving the creation of local training opportunities and good quality local jobs (Warren and Griffiths, 2017).

7.2 Retaining character of communities where people want to live

Area-based retrofit scheme and community owned energy projects can increase the attractiveness of communities (Jones et al. 2019; Warren and Griffiths, 2017). Area-based retrofit schemes can enhance the appearance of the local area, promoting a sense of pride and encouraging residents to actively contribute to creating cleaner, more attractive public spaces (Warren and Griffiths, 2017). Investing in improvements to housing in an area can lead to a cycle of investment in the local area, and increase the attractiveness to investors (Power, 2008). However there is also a risk that altering the appearance of homes in some areas could damage cultural heritage and the character of communities (Shrubsole et al. 2014).

7.3 Building community involvement

As described in Chapter 6, there is some evidence that participatory approaches can help to build involvement and help shape local involvement. By making communities more attractive and building

social engagement and promoting shared values, schemes with significant community involvement can contribute to a newly vibrant culture (Mayne 2018).

7.4 Quality of evidence

This chapter suffers from a scarcity of high quality evidence, asides from the relatively strong evidence on job creation. The findings are overly reliant on scanning for relatively minor mentions in the literature of how housing decarbonisation can contribute to improving an area's attractiveness to retain or attract people and on how to build 'intangible' culture. The evidence on job creation would be improved by linkages to wider literature on how jobs created in Wales have been shown to creating desirable communities where Welsh people want to live and socialise and so contribute to a vibrant culture and language.

7.5 Gaps or research limitations

Little evidence was identified on the effect of co-benefits of housing decarbonisation either for cultural heritage (buildings) or living and creative culture of Wales, including language, stories, and cultural engagement with the local environment.

8 Contributing to a globally responsible Wales

Key findings

- This chapter refers to relevant policy documents on the global responsibilities of Wales to reduce carbon emissions and to promote sustainable development.
- There is strong evidence that interventions to decarbonise homes reduce carbon emissions. However, this is not a co-benefit.
- The primary goal of decarbonising all homes in Wales by 2050 is an important dimension of a globally responsible Wales, enabling the nation to meets its international obligations to act on climate change and to protect the well-being of future generations. Housing decarbonisation would make a significant contribution towards reducing demand-side greenhouse gas emissions in Wales, with housing currently responsible for 15% of all demand-side greenhouse gas emissions. This would bring wider environmental and health benefits valued at a global scale.
- Decarbonising housing would contribute to reducing climate change related health risks associated with air pollution, which have a wider footprint than Wales.
- By contributing to the other Wellbeing Goals, decarbonising homes in Wales can contribute to well-being and sustainable development, supporting Wales' commitment to the United Nations' 17 Sustainable Development Goals (Welsh Government 2019a).

8.1 Carbon emission reductions

Carbon emission reductions is the primary global responsibility to be addressed by decarbonsation activities. As such, carbon emissions reductions achieved by housing decarbonisation activity cannot be considered a co-benefit. Here we briefly report on the evidence identified in this review of carbon emission reductions achievable as a result of housing retrofit actions, decarbonising power generation and heat production for use within the housing sector. The Welsh Government's Arbed schemes aimed to reduce carbon emissions, reduce fuel poverty and support the energy efficiency and renewable energy sector in Wales. Established in 2009, the £60 million Arbed 1 involved retrofit improvements to more than 6,000 socially rented and owner occupied homes in selected low income regeneration areas (Patterson. 2016). Arbed 2 occurred between 2012 and 2015 with a £45 million investment targeting solid wall, off gas properties. Average SAP rating rose from 60 to 69. Total estimated annual carbon savings were reported as 3,025 tonnes per year (ibid). A modelling study of the costs and impacts of a UK-wide domestic retrofit programme to bring all homes to EPC C through energy efficiency measures, funded through grants for low income households and loans for able-to-pay households, estimated the total discounted cost to the government to be £41.6 billion and the carbon savings to be 23.6MtCO2 reductions per annum by 2030, after accounting for rebound effects (Washan et al. 2014). The co-benefits associated with housing retrofit schemes are reported in other chapters.

One pathway to housing decarbonisation is by decarbonising the electricity and heat supply to Welsh housing, by replacing coal, oil and gas fuels with low or zero carbon renewable forms of electricity and heat. However, there is a paucity of evidence regarding the localised co-benefits of this route to decarbonisation. Domestic renewable energy generation, such as rooftop PV, can contribute towards housing decarbonisation (Mayne, 2018). There is limited evidence on the co-

benefits attributable to domestic renewable energy generation, which is generally micro-scale. Newer approaches to achieving housing decarbonisation, such as domestic demand side response interventions, which match domestic energy consumption to production of zero carbon renewable energy generation, offer promise for achieving carbon reductions. (Bradley et al 2013). However, there is to date a paucity of evidence regarding the co-benefits.

8.2 Air quality and health

Pridmore et al (2017) reported that whilst the literature includes numerous mentions of air quality co-benefits from climate change mitigation actions, few report this separately for the building sector. They referenced a 2013 UK Committee on Climate Change (CCC) report that estimates air quality benefits from an UK-wide abatement scenario involving a shift to biomass boilers, biomass district heating, biogas, solar hot water and heat pumps in residential and non-residential buildings and industry, plus a range of building energy efficiency measures. The CCC study estimated the costs of health impacts from emissions of NO_X, SO_2 and PM_{10} for biomass and biogas heating, and the costs avoided from savings in coal, gas and oil. Pridmore et al (2017) reported that the CCC study findings showed the cost of emissions from biomass and biogas boilers partly offset the large savings from avoided coal, oil and gas combustion but still resulted in a large net benefit of £239 million. Although most emissions of external air pollution are from local or regional sources, under certain atmospheric conditions, air pollution can travel across national borders, thereby affecting people far away from its source.[9]

8.3 The contribution to Sustainable Development Goals

By contributing to the other Wellbeing Goals, decarbonising homes can also contribute to well-being and sustainable development, supporting Wales' commitment to the United Nations 17 Sustainable Development Goals (SDGs) (Welsh Government 2019b). The evidence for this is set out in the preceding 'Contributing to…' chapters. The evidence for co-benefits is particularly strong for:

- Contributing to global, national and local economic growth, job creation in the low carbon economy, savings to the Treasury and to the NHS and reduced fuel poverty (see Chapter 2).
- Strengthened community capital and resilience in a transforming energy system (see Chapter 3).
- Environmental benefits from sustainable forestry, where there is use of sustainable building materials and through the avoidance of damage from demolition or use of high carbon materials in new build or refurbishment (see Chapter 3).
- Environmental and biodiversity benefits, particularly from green roofs and green walls. The evidence of such benefits from other intervention types is less well-evidenced (see Chapter 3).
- Improved resilience of homes and communities to the effects of climate change related to extreme weather conditions, including excess rainfall. The evidence on resilience to overheating needs strengthening (see Chapter 3).

[9] Ambient air pollution: Pollutants. https://www.who.int/airpollution/ambient/pollutants/en/

- Improved resilience of the energy system, through contributions to demand reduction and, potentially, domestic demand flexibility, as well as reduced reliance on fossil fuels from non-OECD countries (see Chapter 3).
- Increased equality, by reducing fuel poverty and associated social, health and educational inequalities (see Chapter 4).
- Improved mental health and overall well-being and reduced demand on the NHS (see Chapter 5).

8.4 Quality of evidence

This chapter draws on the strongest evidence from other chapters, as well as referencing other documents on the recognised global benefits of reducing carbon emissions.

8.5 Gaps or research limitations

The contribution of housing decarbonisation co-benefits in OECD countries to the achievement of global sustainable development goals is poorly recognised in international literature, which tends to focus on the importance of affordable access to heating and access to decent homes in developing countries.

This REA did not specifically seek out literature on the co-benefits of carbon reduction at an international scale, but it is recognised that there is a strong and growing body of evidence both on the importance of decarbonising housing (IPCC 2018) and on the co-benefits of climate change action at European (Workman et al 2019) and international scale (Hamilton, Brahmbhatt and Liu, 2017). The literature included limited evidence on the external air quality benefits attributable to housing decarbonisation.

9 Conclusions and implications

Table 4 below provides an overview of the co-benefits identified as contributing towards each well-being goal and a judgment on the quality of the evidence reviewed.

Table 4: Summary of co-benefits and quality of evidence

Wellbeing goal:	**A prosperous Wales**
Co-benefits:	Strong evidence of range of benefits for: a low carbon economy; GDP growth; tax receipts; savings to Treasury, creation of decent, local jobs; local supply chain; training; savings on fuel bills; increases to property value.
Quality of evidence:	**Good**
Wellbeing goal:	**A resilient Wales**
Co-benefits:	Strong evidence of benefits for: increased local economic resilience; increased social capital; grid reliability; and energy security. Mixed evidence on futureproofing homes against the effects of a changing climate. Weaker evidence on local environmental benefits.
Quality of evidence:	**Good**
Wellbeing goal:	**A more equal Wales**
Co-benefits:	Strong evidence of benefits for tackling fuel poverty and associated health, economic and social equality benefits. Weaker evidence on educational benefits.
Quality of evidence:	**Good**
Wellbeing goal:	**A healthier Wales**
Co-benefits:	Strong evidence of health benefits from improved housing for mental health, health of people with existing respiratory conditions; health inequalities and wellbeing. Weaker evidence on savings to NHS and social care.
Quality of evidence:	**Good**
Wellbeing goal:	**A Wales of cohesive communities**
Co-benefits:	Limited evidence of co- benefits relating to this wellbeing. Strongest evidence of indirect benefits from the creation of new local employment.
Quality of evidence:	**Mixed**
Wellbeing goal:	**A Wales of vibrant culture and thriving Welsh language**
Co-benefits:	Limited, indirect evidence of co-benefits relating to this wellbeing goal. Strongest evidence relates to local job creation and attractive communities to retain people living in Welsh towns and villages.
Quality of evidence:	**Weak**

Wellbeing goal:	**A globally responsible Wales**
Co-benefits:	Good evidence of the health benefits associated with reduced air pollution and of contributing to Sustainable Development Goals in Wales. The evidence on indirect contributions to biodiversity and environmental quality outside Wales is weaker.
Quality of evidence:	**Good**

9.1 Applicability of findings to different types/tenure of housing

Most of the findings on co-benefits are not clearly associated with particular housing archetypes. The Arbed schemes mostly included social rented and owner occupied homes in low-income areas, with a particular focus on installing external wall insulation in hard to treat homes. A wide range of associated co-benefits were identified, including job creation, skills and training opportunities, lower fuel bills and reduced fuel poverty, health benefits and community cohesion benefits (Patterson, 2016; Poortinga et al 2018; Warren & Griffiths, 2017).

Ambrose (2015) summarises the particular barriers to decarbonisation in the private rented sector as including a lack of knowledge amongst landlords about the consequences of energy inefficiency and the range of available solutions, lack of direct incentives to invest, housing market factors that deter investment and a lack of associated equity, cultural factors which include general acceptance of poorly performing pre-1919 properties as the norm, transience in the rental property market and low trust amongst landlords in government initiatives. There is, as yet, limited evidence of whether and to what extent overcoming these barriers can release co-benefits.

9.2 Barriers to achievement of wider benefits

Ambrose (2015) draws on a literature review and qualitative interviews to identify barriers to housing decarbonisation action by private landlords including lack of knowledge; absence of financial incentives; local housing market factors and cultural factors.

Scalability is a key challenge to achievement of co-benefits, alongside achievement of decarbonisation. This applies to large scale retrofits which require sufficient available specialist retrofit skills and capacity (Patterson 2016), behaviour change programmes (Pridmore et al 2017), as well as for newer technologies and service that have so far at best been tested in small scale trials (Qadrdan et al 2016; Murtagh et al 2014).

Empirical studies identified barriers to the delivery of high quality, cost-effective and timely large-scale energy efficiency schemes, including perverse financial incentives favouring demolition over refurbishment (Power 2008); issues with control of capital costs and poor quality of implementation (Patterson 2016); regressive effects of financing mechanisms for improvements (Mayne 2018), the 'hassle factor' of involvement in redevelopment (Green & Gilbertson 2018), reluctance to take on costs associated with schemes (Frontier Economics 2015) and concerns about payback period and the resale effect of taking on a loan (Ambrose 2015). However, these studies did not directly address the effect on achievement of co-benefits.

The literature included identification of barriers to the effectiveness of behaviour change as a means of improving energy efficiency, including: incomplete or uncertain information to support well-informed choices (Pridmore et al 2017); weak motivational factors and rebound effects which result in reduced financial savings to the households as well as limited energy reductions (Renz & Vogt 2015). Behavioural barriers are identified as preventing investment, including those associated with lack of interest, low awareness, risk aversion and lack of trust (Frontier Economics 2015). This can also affect willingness to participate in demand response (Bradley et al.2013). The interaction of time-dependent household routines, such as family mealtimes, with demand-side response peak pricing, was identified as likely to result in inequitable outcomes, disadvantaging lower income households, people with poor health, families and working mothers (Murtagh et al 2014).

Market reforms, including to make sure that domestic consumers gain financial benefits and to make sure that wider societal benefits are achieved from demand reduction are identified as important levers to motivate consumer participation in demand reduction (Bradley et al. 2013). Implementation of smart metering rollout and the marketing of other new technologies in ways that build trust and maximise consumer acceptability and satisfaction are predicted to be important requirements for demand reduction to contribute to domestic carbon reduction (ibid).

9.3 Levers to achieve wider benefits

Levers to encourage action in the private rented sector

Ambrose (2015) identified factors which might motivate landlords to improve the energy performance of their properties. These included recognition that high energy bills might threaten the ability of tenants' ability to pay their rent. However, a landlord's response to this might depend on the dynamics of the local rental market. The ability to maintain an attractive property could be a motivating factor to protect their asset and keep good tenants. Where improvements achieved both energy efficiency benefits and made their property more attractive, it was felt landlords might be more likely to act. However, these factors were theorised and not proven.

The MEES regulations set a trajectory for driving improvements in the energy efficiency performance of the private rented sector in England and Wales from 2018 onward.[10] However, as yet, there is a paucity of evidence of the effectiveness of this legislation in achieving substantive improvements, or of any associated co-benefits. Rent Smart Wales is a central register for landlord registration. This will support accurate identification of private rented properties, facilitating enforcement of MEES regulations.

The longer established Housing Health and Safety Rating System (HHSRS) provides a basis for councils to require landlords to make improvements to very cold homes. However, this REA did not identify any studies that reported co-benefits as a result of enforcement action resulting in improvements to the energy efficiency of homes as a result of HHSRS.

The review did not identify other sector-specific levers for action.

[10] See https://www.gov.uk/guidance/domestic-private-rented-property-minimum-energy-efficiency-standard-landlord-guidance [Accessed 11/09/2019]

Levers to maximise equity and health benefits

Several studies report that targeting can help maximise the achievement of benefits for health and equity, including fuel poverty (Campbell 2014, Frontier Economics 2015). Campbell (2014) identifies a whole-building approach and following safe retrofitting procedures, as well as safeguarding to manage the risks of pollution associated with renovation as important to protect the achievement of health benefits and community benefits.

Government procurement policies to require use of local supply chains of goods and services, training and apprenticeships were identified as ways to make sure local economic benefits from energy efficiency are maximised (Jones et al 2019; Patterson 2016). There was limited acknowledgement in the literature of the need to consider appropriate retraining to minimise job losses in the shift from traditional carbon-intensive energy jobs to a low carbon economy (Jones et al 2019). A co-ordinated area-based approach, as used in the Arbed schemes, was identified as a means to enable local markets to mature. One report suggested, with reference to the Arbed schemes, that a direct government approach would be favourable to minimise transaction costs, by making use of local government knowledge of housing stock and their occupants (Frontier Economics 2015).

In considering the growing attention to domestic demand side response as a means for enabling decarbonisation, Murtagh et al (2015) conclude that more equitable approaches to shifting peak demand require consideration, making use of technological, economic and behavioural insights.

9.4 Likelihood of achieving range of wider benefits

The review yielded very limited direct evidence regarding the likelihood of achieving wider benefits, though it did identify factors relevant to determining the likelihood of achieving wider benefits. This section draws on wider general literature and wider contextual knowledge in addition to the literature included in the REA.

The Welsh Government's declaration of a climate emergency and setting of ambitious specific targets, galvanised by a substantive recent increase in global public awareness and higher prioritisation of climate change, are actions likely to be supportive of public acceptance of action and therefore achievement of co-benefits. The ability to demonstrate and communicate wider public co-benefits is likely to help strengthen public support for housing decarbonisation in Wales. On the other hand, public scepticism regarding past schemes may increase public resistance to the value of housing decarbonisation and this could detract from the achievement of certain co-benefits, such as increased community cohesion and resilience.

Direct economic benefits of job creation and induced economic spend are relatively certain benefits and can be relatively easily predicted using recognised Green Book methodologies based on the amount of investment. Stronger evidence of health benefits are associated with schemes targeted at households with existing health inequalities or determinants of poor health, including low income households and areas which rank higher in terms of relative multiple deprivation.

Within the energy sector, reform of regulations and strong messaging by Ofgem and BEIS to industry to make changes towards a smart system favours the likelihood of new services enabling domestic consumers to participate moving forward (BEIS & Ofgem 2019).

Uncertainty around the role of community energy and general shrinkage in this sector make it less likely to be able to engage in and drive housing decarbonisation. This makes it less likely that some of the broader community benefits will be achieved. Likewise, the effects of austerity on council budgets and capacity are likely to impede the ability of local authorities to drive activity. This also makes it less likely that some of the broader community benefits as well as equality benefits will be achieved.

Promising findings from demonstrators and innovation projects, as led by network operators and with support of Welsh Government, increases the likelihood of inward investment into Wales to deliver decarbonisation (ADRA & CSE, 2019; Wales & West Utilities, 2018). Likewise, the experience from the WHQS, Arbed and Nest schemes means that, compared with other parts of the UK, Wales is relatively well-placed to further build the necessary skills and capacity to deliver decarbonisation in tandem with wider co-benefits.

9.5 Timeline considerations

Very limited direct evidence was identified in the REA regarding timelines. This section draws on wider general literature and wider contextual knowledge in addition to the literature included in the REA. Factors which would impede rapid achievement of co-benefits are similar to those which affect likelihood of achievement. Factors which may impede timely achievement include:

- Skills and capacity shortages in specialist retrofit to undertake large-scale delivery at pace to a high quality that builds confidence for households to participate in programmes.
- Rates of domestic low carbon generation installation are low in Wales, placing households at a potential disadvantage for participating in emerging opportunities which support decarbonisation of the energy system. Newer decarbonisation technologies, particularly in heat decarbonisation and domestic demand response are still at trial or demonstrator stages and so are unlikely to factor in wide-scale rollout until these technologies and the supporting business models are better developed.
- Low rates of smart meter rollout are likely to impede some low carbon opportunities.
- Large scale energy efficiency housing retrofits are likely to be most able to proceed in a timely fashion, assuming available capital and revenue funding as the approach is well understood and the co-benefits are well understood. However, there is still likely to be a time-lag before some wider benefits are achieved and for those impacts to be detectable at scale. This is particularly the case for physical health improvements and measurable reductions in fuel poverty rates. Community resilience and community cohesion benefits are also likely to only become measurable over a longer timescale.

9.6 Key evidence gaps for consideration and further research

Heat decarbonisation co-benefits

A key evidence gap concerns the co-benefits associated with decarbonisation of heat. This is a key area of challenge for achieving decarbonisation and will require consideration of the potential co-benefits and co-risks. Wales has large numbers of off-gas properties where electrification of heat and decarbonisation of the electricity sector may prove a suitable solution. Other approaches to decarbonisation being trialled include heat networks and hybrid heat pumps. Demonstrator projects, such as Bridgend's Smart systems and heat demonstrator district heating scheme using mine water (ADRA & CSE 2019; Thomas and Manju, 2018) and Wales and West Utilities Freedom Project (2018) hybrid heating systems have not yet yielded findings on the co-benefits, though there has been active consideration of the outcomes people are seeking from a 'heat as a service', such as comfort (ADRA & CSE 2019).

Housing retrofit at scale and co-benefits over a longer term frame

Much of the evidence included in this review focuses on the benefits achieved by targeted domestic retrofit programmes with targeting based on characteristics of the property, occupants, or neighbourhood. The Decarbonisation of Homes in Wales Advisory Group (2019) highlights that to meet decarbonisation targets all homes in Wales will need to reach an EPC Band A, and recognises not all homes will be able to achieve this. A retrofit programme of this combination of scale and ambition has never been delivered before – the most relevant scalable examples in Wales are the WHQS, Arbed and Nest schemes. Whilst evidence from these and smaller programmes indicates the potential co-benefits, there is necessarily uncertainty about how these will scale up, the extent to which they will be mutually reinforcing or the potential risks of harm of different types (or co-risks). The co-benefits realised by targeted programmes cannot be assumed to be replicated in programmes rolled out more widely or where delivery is in areas with different dwelling type, tenure, household or community characteristics. There is also a lack of empirical large-scale evidence on co-benefits over time following intervention delivery. It is likely that there is a considerable time-lag for some co-benefits to be realised and identifiable, whilst other co-benefits may prove short-lived.

Behavioural change

This REA has included some evidence on interventions that have included behaviour change components or evidence reporting behaviour as an explanatory factor for why co-benefits are or aren't achieved. However, this is relatively patchy. There is wide recognition that the scale of the change required will require a transformation in behaviours, amongst those involved in delivery of interventions as well as residents and other stakeholders. Further empirical research on behavioural change can help identify ways to achieve wider co-benefits from interventions. The research programme of the Centre for Climate Change and Social Transformations (CAST) at Cardiff University is likely to be important in contributing to such research.

Co-benefits of newer and less familiar low carbon technologies and services

The REA found limited evidence on co-benefits resulting from deployment of some of the newer or less familiar technologies being considered as possible solutions for achieving decarbonisation in the

domestic sector. Examples of such technologies include heat pumps, smart appliances, demand side response and heat networks.

Private rental and owner occupier sectors

The REA found scant evidence on co-benefits specific to the private rental and owner occupier sectors. Given the urgency to make progress, it may be appropriate to plan for primary evidence collection as part of trial programmes targeting these sectors, particularly to support investment to improve the energy efficiency of the private rental sector, which has the worst rates of fuel poverty in Wales. Funded programmes should include an evidence gathering and evaluation component. This could include a focus on behavioural change and to understand how co-benefits are shared between landlords, tenants and more widely within the neighbourhood. This would align with and support progress towards the trajectory of tightened MEES regulations.

For the owner-occupier sector, there may be potential to conduct a retrospective re-analysis of the evidence to better understand the co-benefits associated with the owner-occupier sector from past Arbed and Nest schemes.

Empirical evidence of the financial savings to the health & social care sectors

The lack of large scale empirical evidence of savings to the Welsh and/or UK health and social care sectors from investment in energy efficiency remains a significant gap. There are practical, methodological and financial barriers to a credible piece of research being successfully commissioned and completed. It would require collaboration between academic, health and delivery bodies.

Overheating

A specific gap in the literature concerns empirical evidence on the effectiveness or not of retrofit energy efficiency interventions as a way to mitigate against risks of overheating in existing homes, particularly for those most at risk of adverse effects, including older people, people with existing health conditions, young children and babies.

Educational attainment

A specific gap in the literature concerns empirical evidence on whether improvements to the energy efficiency of homes feeds through to improved attendance and narrowing the gaps in educational attainment amongst children through their educational career, including for children in low income households and children with asthma or other health conditions.

Cohesive communities and vibrant culture

The evidence of co-benefits contributing to these well-being goals was weaker or more mixed. A deep dive focused literature review on intangible ‘felt’ community and cultural benefits that result from either housing retrofit programmes or housing-related renewable energy projects may yield further evidence. This should include critical review of smaller scale (likely qualitative) studies from the charitable sector or community energy sectors. However, it is possible that there is a lack of suitable quality evaluations of smaller scale schemes.

Co-benefits associated with different types of housing

This REA identified limited evidence that addressed the primary research question of how the evidence applies to different types of housing. A focused search may yield additional small-scale qualitative studies to enrich understanding of co-benefits associated with interventions targeted at the main types of existing housing found in Wales, including the pre-war mostly Victorian mid-terrace houses, smaller inter-war semi-detached houses, post-war semi-detached houses that make up around 35% of Welsh housing stock (Green et al 2018). Alternatively, a case-study design to revisit and examine the co-benefits achieved by interventions which have targeted such properties would be beneficial. This should include consideration of the co-risks as well as the co-benefits, for example to ensure understanding of the harmful effects of unsuccessful retrofits on hard-to-treat homes and the consequences for uptake of future interventions.

Possible areas for additional narrow 'deep dive' literature reviews

The scope of this REA was broad and shallow across multiple intervention types and multiple co-benefits. A number of additional narrowly focused 'deep dive' rapid evidence reviews may yield further supporting evidence on particular areas of potential co-benefits. Suggested areas to support better evidencing of co-benefits include:

- Prosperous Wales: Empirical (non-modelled) evidence on lasting job creation, net employment effects and distributional impact of employment and other economic effects from national retrofit energy efficiency programmes or more general housing improvement programmes.
- Resilient Wales: Local environmental and biodiversity benefits from circular economy approach to retrofit and housing quality improvements, involving sustainable procurement, re-use of materials and avoidance of demolition. The use of more specialist search terms may yield additional relevant evidence on these benefits, although it may require inferences to be made from empirical evidence on non-retrofit interventions.
- Globally responsible Wales: International literature of the global co-benefits of climate change mitigation actions as framed by the sustainable development goals. This would enable the contribution to the global responsibilities of Wales, beyond decarbonisation itself, to be better evidenced.

Longitudinal research

Longitudinal studies could generate useful additional evidence of longer term co-benefits, including social, economic, health, and community resilience benefits.

Longitudinal research, which involves gathering data for the same cohort of individuals (or households or dwellings) repeatedly over a period of time, extending over years or decades, can be a valuable way of understanding the longer term co-benefits of housing decarbonisation at a household or dwelling level. The Welsh Housing Stock Analytical Resource (HSAR) brings together data on the characteristics, fabric condition and energy efficiency of the housing stock in Wales. It anticipates linking administrative, survey and modelled data at property level to inform the evidence base on housing deprivation and related policy areas of health, education and the economy. This

provides a potentially powerful tool for use in analysis to understand the effects of improved energy efficiency on social, health and economic co-benefits.

Make use of evidence planned or already commissioned by UK and Scottish governments

Welsh Government should keep abreast of planned evaluation or other research commissioned by the UK government and the Scottish Government and where possible, influence the design of studies so that they include measurement and reporting on co-benefits. Potential studies of interest include planned impact and process evaluations of large scale energy efficiency programmes in Scotland. Process evaluations of programme delivery are likely to yield useful evidence on best practice and pitfalls to avoid in the design and delivery of programmes that maximise the achievement of co-benefits.

Choice of research method

Where Welsh Government decides to commission or undertaken new primary research, consideration should be given to the appropriate type of research to gain understanding of the co-benefits. Controlled trial methods may not prove the most effective means of gaining an understanding of those co-benefits which are achieved through complex indirect causal pathways and for which it is harder to identify objective measures of impact. A good example of this is community resilience. Qualitative, including more anthropological, research methods may be more appropriate.

9.7 Implications for next steps

A number of implications for further action are described below.

Sharing findings within Welsh Government

On the basis of current evidence identified by this REA, economic, health, resilience and equality (mainly fuel poverty) co-benefits provide the strongest basis to support the carbon reduction based arguments for investment in housing decarbonisation. Better evidence on educational and community cohesion benefits would help add to the case, as would evidence to show the lasting nature of benefits.

Collaborate effectively with Welsh Government Smart Living team to identify co-benefits

The newer areas of heat decarbonisation and demand flexibility will require ongoing attention to understand and shape their contribution to co-benefits as well as decarbonisation. The Welsh Government's Smart Living programme and the Cardiff University-led Flexis programme are examples of ongoing work in Wales to better understand these areas of activity and so build the evidence base on co-benefits.

Apply insights on levers, dependencies and barriers to policy and programme development

This evidence review has identified valuable insights regarding levers, dependencies and barriers to achievement of co-benefits. Policy and programme developers should pay attention to these insights, many of which come from evaluations of affordable warmth programmes in Wales and England.

Promoting action in the private rental sector

An important area for attention concerns the design and effective employment of policy and other levers to motivate retrofit activity in the private rental sector, particularly to support investment in improving 'hard to heat' properties.

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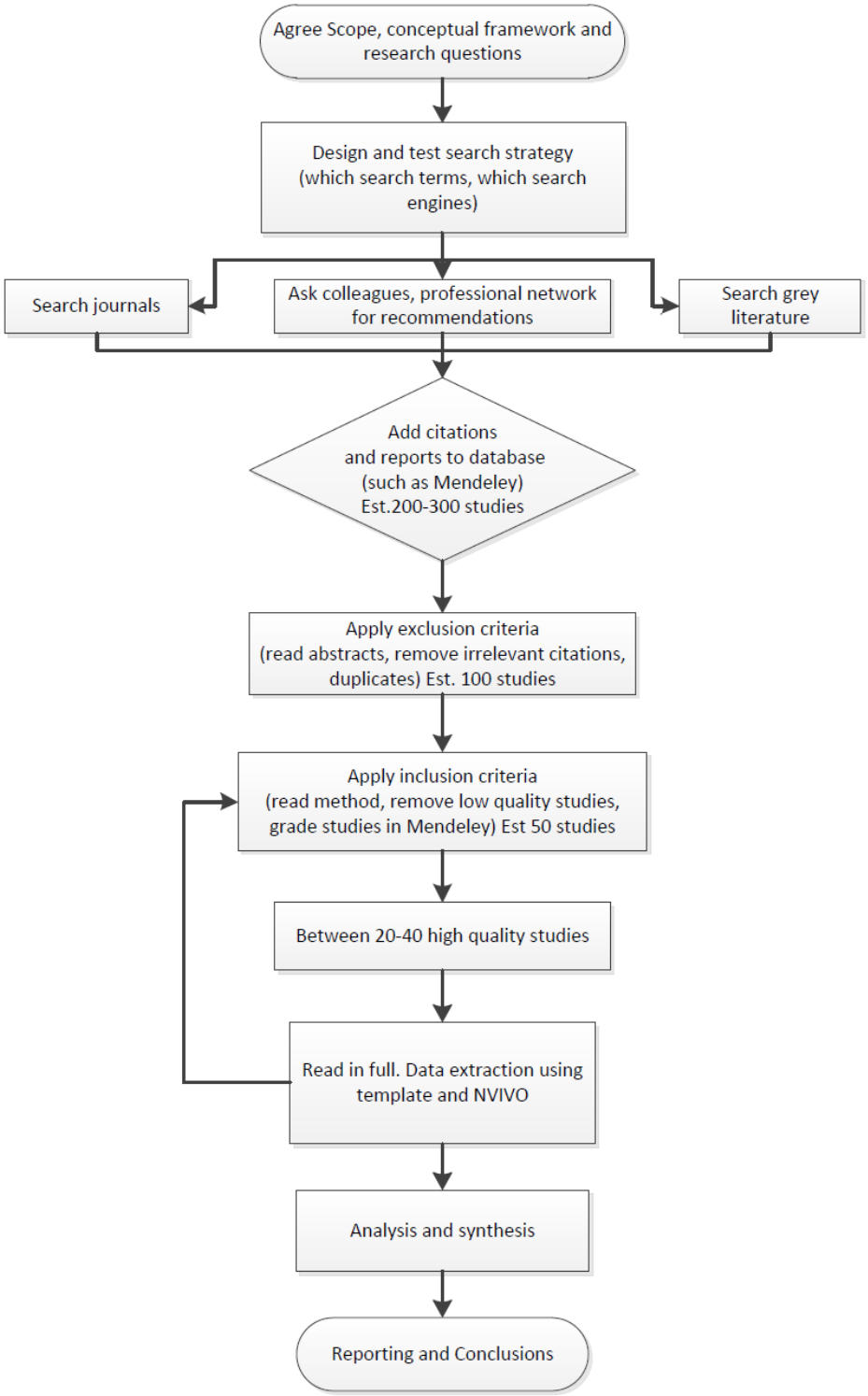
Appendix A Search Strategy and outputs

Summary of research process

The study used a Rapid Evidence Assessment (REA) method to gather and synthesise evidence for the co-benefits of decarbonising homes. REA is systematic approach to literature review. A summary of the research process is shown in the flow chart (see Figure 1).

Figure 1: Summary of research process



Scope

The scope of interventions to include for consideration was agreed with Welsh Government prior to commencing the search. The interventions included and excluded are show in Table 5.

Table 5: Intervention types 'in' and 'out' of scope

Measure	In scope?
Retrofit Good practice / best practice/ heritage / rural off-grid	Yes
New build Fabric first / best practice	No
Insulation	
Any	Yes
Windows	
New – more energy efficient (UPVC; triple timber)	Yes
Secondary glazing	Yes
Air tightness	Yes
Domestic / locally viable renewables	
Air source heat pump	Yes
CHP	Yes
PV	Yes
Electric battery/battery storage	Yes
Wind – domestic / local scale only	Yes
Solar thermal	Yes
Heating	
Gas central heating – A-rated boiler	Yes
Underfloor - Heat pump	Yes
Heat storage	Yes
Electrification of heat (which requires decarbonisation of electricity supply)	Yes
Combi boiler – heat pump – solar hot water	Yes
Heating controls – thermostat / TRV/programmer / smart thermostat	Yes
Any boiler / heating system replacement with a more efficient model (including more efficient gas or oil boilers)	Yes
District heating serving housing	Yes
Other in-home measures	
Ventilation – MVHR / natural	Yes
Energy efficient appliances (eg dishwasher)	Yes
Energy monitors (including smart meter IHD)	Yes
Smart controls / smart home systems	Yes
Behaviour change support	
Home energy advice services	Yes
Behaviour change support associated with eg installation of measures	Yes
Stand-alone behaviour change initiatives around home energy use (eg campaign)	Yes
Wider / related measures	

Electric vehicles (including home charging points)	No
National grid low carbon electricity generation	Yes

Search strategy

Evidence was found through a systematic search in Google Scholar search engine, through requesting evidence from CSE's professional network and through the Welsh Government's Decarbonisation Library. The following search terms were used in Google Scholar search engine (Table 6). The search terms were designed and tested to find evidence of co-benefits relating to each of the Wellbeing Objectives.

Table 6: Systematic search terms and results

Search string	Papers included from first 30 hits	Date searched
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit*	27	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +job*	29	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +(econom* or growth)	27	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +(skill* OR employ*)	24	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* + (flood* OR cool* OR adapt*)	16	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +(ecolog* OR ecosystem OR biodivers*)	18	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +(natural environment OR natur*)	12	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* + (warm OR health)	39	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +("fuel poverty" OR cold)	36	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +(*equality OR fair)	22	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +just*	18	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +(depriv* OR socio*)	27	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +(learn* OR apprent* OR young OR educat*)	16	03/07/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +(communit* OR cohes* OR safe)	27	18/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +local*	19	19/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* + (place OR cultur* OR heritage)	22	19/06/2019

("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +language	24	19/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* + (art* OR sport OR hobby)	23	19/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + *benefit* +world	25	19/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + behaviour*	23	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + "behaviour* change"job*	14	20/06/2019
("decarbon*" OR "energy efficiency" + "behaviour* change") + impact*(econom* or growth)	16	20/06/2019
("decarboni*" OR "energy efficiency") + (home OR domestic OR hous*) + impact* + behaviour*(skill* OR employ*)	14	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + impact* OR *benefit* + ("energy advice") (flood* OR cool* OR adapt*)	12	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + impact* OR *benefit* + retrofit(ecolog* OR ecosystem OR biodivers*)	15	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + "electricity grid"(natural environment OR natur*)	10	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + "national grid" (warm OR health)	8	20/06/2019
("low carbon" OR decarbon* OR "energy efficiency*") + (home OR domestic OR hous*) + (impact* OR *benefit*) + "off grid*"("fuel poverty" OR cold)	9	20/06/2019
("low carbon" OR decarbon* OR "energy efficiency*") + (home OR domestic OR hous*) + (impact* OR *benefit*) + "heat*"(*equality OR fair)	11	20/06/2019
(decarbon* OR "energy efficiency*") + (home OR domestic OR hous*) + (impact* OR *benefit*) + "heating system*"just*	8	20/06/2019
(decarbon* OR "energy efficiency*") + (home* OR domestic OR hous*) + (impact* OR *benefit*) + ("smart meter*" OR "energy monitor*") (depriv* OR socio*)	13	21/06/2019
(decarbon* OR "energy efficiency*") + (home* OR domestic OR hous*) + (impact* OR *benefit*) + insulation(communit* OR cohes* OR safe)	8	20/06/2019
("low carbon" OR decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + refurb*local*	11	20/06/2019
("energy saving" OR "emission* reduction*) + (home OR domestic OR hous*) + (impact* OR *benefit*) (place OR cultur* OR heritage)	10	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + (resilien* OR adapt*)language	11	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + revenue (art* OR sport OR hobby)	10	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + well-being	15	20/06/2019
(decarbonisation OR "energy efficiency") + (home OR domestic OR hous*) + (impact* OR *benefit*) + invest*	12	21/06/2019

("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact)	13	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (system OR grid) + (*benefit* OR impact)(econom* OR growth OR job OR skill OR employ*)	13	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact) (flood* OR cool* OR adapt* OR ecolog* OR ecosystem OR biodivers* OR natural environment OR natur*)	1	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact)(warm OR health fuel poverty" OR cold)	22	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact)(*equality OR fair OR justice OR depriv* OR socio*)	6	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact)(learn* OR apprent* OR young OR educat*)	15	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact)(communit* OR cohes* OR safe OR local)	14	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact) (place OR cultur* OR heritage OR language)	2	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact) (art* OR sport OR hobby)	7	03/07/2019
("low carbon" OR decarbonisation OR renewable) + (electric* OR system OR grid) + (*benefit* OR impact)(world OR reputat* OR global OR International)	7	03/07/2019

Further papers were identified through the Decarbonisation library. Grey literature (non-academic) was identified through searching online on websites known to CSE as producing reports around decarbonising homes, and co-benefits. Individuals and organisations in CSE's professional network were also contacted to ask for evidence. The total number of papers identified is shown in

Table 7.

Table 7: Number of papers identified

Source	Papers (before removing duplicates)
Systematic search (Google Scholar)	573
Welsh Governments Decarbonisation library	220
CSE professional network and grey literature search	18
Total	**811**

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