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## Understanding the decarbonisation of housing: Wales as a case study

To cite this article: E Green *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **329** 012001

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# Understanding the decarbonisation of housing: Wales as a case study

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**Abstract.** International targets requiring UK nations to reduce carbon emissions by at least 80% of 1990 levels by 2050 were made obsolete in 2019. The Climate Change Act now commits UK government to reducing greenhouse gas emissions by at least 100% of 1990 levels by 2050. This includes more stringent emissions targets for the devolved administrations. Welsh Government is responsible for the delivery of decarbonisation in Wales. The Welsh housing stock, among the oldest and least efficient in Europe, produces 21% of national carbon emissions. The CCC report recommends that Wales target no less than a 95% reduction in carbon emissions by 2050. This research explores how policy could deliver this scale of emissions reduction, by predicting the impact of established and emerging ‘best practice’ retrofit solutions on the existing housing stock. Fourteen recurring dwelling ‘types’ are identified within the Welsh housing stock (based on physical metrics, condition and tenure) using large data sets. Appropriate retrofit ‘narratives’ are established and then simulated for each of the fourteen dwelling types. Their impact is measured in terms of capital cost, primary energy use, fuel bills, and carbon emissions. By exploring the impact of a range of approaches to retrofit, and by considering different scenarios for clean energy supply, this research has informed the ongoing development of a route map for delivering decarbonisation targets in Wales.

## 1. Background

Longstanding international targets required UK nations to reduce greenhouse gas emissions by at least 80% of 1990 levels by 2050. Welsh Government committed to these targets via the Environment (Wales) Act 2016. However, following widespread acknowledgement of a climate emergency in 2019, and subsequent publication of a report by the Committee for Climate Change [1], UK government is now committed to reducing greenhouse gas emissions by at least 100% of 1990 levels (net zero) by 2050, significantly increasing the scale of the challenge.

The CCC report recommends that Wales deliver a 95% reduction in greenhouse gases by 2050. The Welsh housing stock produces 21% of national carbon emissions (compared with 29% of UK carbon emissions, and reflecting the relatively high level of emissions from industry in Wales). Key factors affecting the challenge of decarbonising the Welsh housing stock include:

- Cleaner electricity generation is a clear achievement of the last decade. However, progress in this sector masks a failure to decarbonise other sectors, including housing. The UK is not on course to meet the legally binding fourth and fifth UK carbon budgets [2], and will not do so unless risks to the delivery of existing policies are reduced significantly and new policies go beyond achievements to date.
- The composition of the Welsh housing stock has been stable for the last two decades, with a significant increase only in the private rented sector. Low rates of replacement and an



underperforming housebuilding sector mean that more than 90% of existing homes are predicted to remain in use by 2050.

- Welsh housing is among the oldest and least efficient in Europe. One third of homes were built before 1919. Just 6% were built in the last 30 years (as of 2016), increasing energy demand for heating and reducing comfort. Despite energy efficiency initiatives, almost a quarter of households currently experience fuel poverty.
- Welsh housing is varied in terms of type, age, physical form and construction. Dwellings have been modified over time to create a diverse stock of varying quality and condition. There is no single ‘solution’ for such a varied housing stock. However, a study of the potential to retrofit the more common dwelling ‘archetypes’ reveals appropriate pathways for decarbonisation.

## 2. Method

The research underpinning this paper was commissioned by Welsh Government in two stages: Stage 1 produced the ‘what works’ scoping review (see Section 3). This review of academic and grey literature identified forty domestic retrofit case studies where there was clear evidence of energy and emission reductions. For discussion purposes, retrofit actions were classified according to key themes: Thinking strategically; Building fabric; Renewables; Services; Financial; Supply chain; People. An assessment was made of each retrofit action in terms of confidence and timescale. This enabled a further classification of retrofit actions into ‘what works’, ‘needs exploring’ and ‘big challenge’ categories.

Stage 2 began with a statistical review of existing data (including the VOA data set, the EPC dataset 2016 [3] and the Welsh House Condition Survey 2018 [4]) to establish dwelling archetypes that collectively represent the Welsh housing stock. Modelling the housing stock using archetypes is a well-established method [5], and is particularly useful when modelling retrofit options [6]. Fourteen dominant dwelling types were identified and modelled in SAP [7] (see Section 4: Modelling the Welsh housing stock). These models were used to simulate the Welsh housing stock in 1998, 2018 and 2050. To simulate the condition of the stock in 2050, the Stage 1 review was used to establish four distinct retrofit ‘narratives’ for each dwelling type. The four narratives simulated were 1) retrofit limited by historic building fabric, 2) retrofit to a standard commensurate with current UK Building Regulations, 3) retrofit to a standard commensurate with SAP90, and 4) retrofit to SAP90 in an off-grid situation. To assess the significance of decarbonisation of energy supply via the national grid, three energy supply ‘scenarios’ were also considered: 40% clean energy supply, 60% clean energy supply and 80% clean energy supply.

The resulting research (see Section 5: findings) provides a collection of retrofit simulations which broadly reflect the Welsh housing stock. Each dwelling model describes the impact of the four retrofit strategies in terms of capital cost, energy use, fuel bills and carbon emissions. Each model also considers the three distinct energy supply scenarios. These models have been used to draw conclusions about the potential to decarbonise the Welsh housing stock through retrofit. The conclusions have been used to shape recommendations regarding the ongoing development by Welsh Government of a route-map for decarbonisation. Key recommendations are outlined and explained in Section 6.

## 3. ‘What works’: the Stage 1 review

The key objective of the Stage 1 scoping review was to begin understanding possible pathways towards decarbonisation of the existing Welsh housing stock by establishing ‘what works’: a database of retrofit actions with an empirical basis for assessing their effectiveness in terms of capital costs and impact on energy efficiency and carbon emissions, alongside an understanding of the challenges likely to reduce or resist their effective implementation. Key components of the review include:

- A review of Welsh policy and housing statistics, to develop understanding of context.
- A database of 40 ‘best practice’ retrofit case studies with empirical evidence.
- A review of relevant literature from academic, governmental, industry and advisory sources
- A questionnaire survey, directed towards a wide range of stakeholders.
- The assembled literature was scrutinised to ensure relevance (to Wales) and replicability.
- Additional focussed searches were carried out when a gap was found in the literature.

40 case studies were selected based on their relevance to the decarbonisation of Welsh housing, and on the quality of underpinning empirical evidence, with the aim of finding at least one case study to represent each known retrofit action. Many of the case studies are located in Wales because this increases their relevance. Most case studies are located in the UK, with only a small number overseas. A number of the case studies were associated with retrofit programmes or funding streams, notably the Retrofit for the Future and WEFO funding programmes. Each case study also explains the key challenges that were encountered.

To develop appropriate strategies for decarbonisation over the next thirty years, pathways will need to combine tried and tested retrofit actions (‘what works’) with actions that are not currently fully understood. Literature was therefore reviewed from a wide range of sources, with the intention of capturing more speculative ‘blue sky’ thinking. 46 published pieces of literature were reviewed, including academic papers, industry standards and best practice advice, stakeholder reports and guidance for policy-makers.

Analysis of case studies and literature identified recurring retrofit actions, and discussed the underpinning understanding and applicability of each, in terms of ‘timescale’ (short term, medium term, long term) and ‘confidence’ (anecdotal, documented and understood). Combined within a simple matrix, the retrofit actions were grouped according to ‘what works’, ‘needs exploring’ and ‘big challenges’:

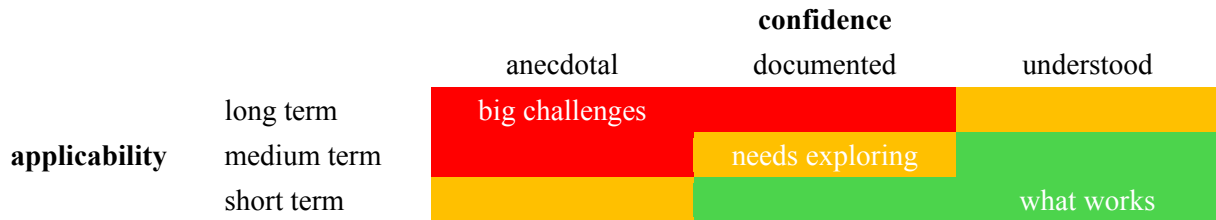


Figure 1. Grouping common retrofit actions into a ‘what works’ classification

While the Stage 1 scoping review [8] cannot be considered to be comprehensive, it captures the breadth of current, relevant practice and exploration in the professional and academic domains. However, for this resource to remain useful, it must be updated regularly with emerging best practice.

#### 4. Modelling the Welsh housing stock

The primary aim of the Stage 2 research was to understand how the nature of the Welsh housing stock informs the development of a strategy for reducing carbon emissions from the housing sector, and establishes reasonable limits for decarbonisation, by connecting the lessons learnt in the Stage 1 review to the specific context of the Welsh housing stock.

To do so, it was necessary to develop a taxonomy of commonly occurring dwelling archetypes that collectively represent the makeup and condition of the existing Welsh housing stock. SAP models of these archetypes were then used to simulate the decarbonisation of the housing stock using understood approaches to retrofit. Implications for energy efficiency, fuel costs and affordable warmth were considered to be an important part of the modelling process.

Two data sets were used to establish the dwelling archetypes. A large, low level detail dataset from the Valuation Office Agency (VOA) was combined with a smaller, high detail dataset from the Welsh Housing Condition Survey (WHCS), related to circa 2,500 dwellings within the Welsh housing stock (collected 2016-2018), to provide a breakdown by dwelling type and age, as outlined below:

**Table 1.** Fourteen archetypes collectively represent 84% of the Welsh housing stock.

	End terrace	Mid terrace	Semi-det.	Detached	Flat	Total
Pre 1919	type 1, 3%	type 2, 9%	type 3, 4%	type 4, 7%		23%
1919- 1944			type 5, 5%			5%
1945- 1964			type 6, 10%			10%
1965 - 1990	type 7, 4%	type 8, 6%	type 9, 10%	type 10, 9%	type 11, 4%	33%
Post 1990			type 12, 5%	type 13, 7%	type 14, 1%	13%
Total	7%	15%	34%	23%	5%	84%

The physical characteristics associated with each archetype are considered to be constant, and enabled digital models to be developed for each dwelling archetype. The modelling techniques used in this report are based on the Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP). The outcomes of SAP are based on the energy required for space heating, water heating, lighting and contributions from renewable technologies. This energy requirement is then used to predict the energy costs and associated Carbon emissions. (A spreadsheet version of the SAP 2012 9.92 worksheet has been developed by the WSA and tested against approved software Stroma FSAP 2012. The spreadsheet version allows the modelling of different fuel costs and emissions rates, which is critical to understand the different outcomes for 1990 and the three future grid scenarios.)

The fourteen dwelling models were then used to evaluate the impact of future retrofit on carbon emissions by comparing the performance of each dwelling as it was in 1990, as it currently performs, and as it might perform in 2050. Further information was needed to simulate the condition of each archetype at these three points in time. This data came from three sources:

- Historic data for the 1990 'baseline' condition came from the United Kingdom housing energy fact file [10]
- Data for the current condition (2016) came from the EPC data for Wales (2016) [3], which represents circa 60% of the total Welsh housing stock (collected over a 9 year period).
- To develop a model for 2050, four retrofit narratives were developed. Retrofit actions were selected based on lessons learnt from the Stage 1 review, developing a specification for each narrative. Each narrative was designed to represent a viable approach for part, or all, of the Welsh housing stock.

**Table 2.** Four retrofit narratives developed from the Stage 1 review.

Good practice	Actions are driven by best value – in terms of affordability, cost effectiveness, and availability of skills and resources in the current marketplace. Meets current Building regulations, indicative SAP rating of 87.6.
Best practice	Assumes an aspirational client or owner occupier, likely to be more concerned with long term quality than short term cost. Environmental impact is a priority. Exceeds current Building regulations, indicative SAP rating of 89.4.
Heritage	Actions are constrained, e.g. as a result of listed building status or location within a conservation area. Impact on dwelling fabric is assumed to be challenging. Indicative SAP rating of 71.
Rural	Location is assumed to dictate off grid energy solutions. The focus is on energy conservation and use of locally viable renewables. Indicative SAP rating 89.8.

The retrofit of each of the fourteen dwelling types was explored in terms of capital costs, and its impact on energy demand, fuel costs, and carbon emissions. Overheating was also investigated. The capital cost data associated with each retrofit action were provided by cost consultant Lee Wakemans. Predicted costs are based on current cost data and recent, relevant case studies. Some costs are assumed to vary with dwelling size, and others are assumed to be static.

By combining the results arising from each individual dwelling type in their representative proportions, it was possible to illustrate the degree to which potential modifications to the Welsh housing stock could achieve carbon emission reductions, along with associated impacts on energy use and capital cost. The results of this modelling enabled a balanced discussion of approaches to decarbonisation that considers carbon emissions alongside capital costs and impact on fuel bills for occupants.

## 5. Findings

This paper explores retrofit actions that directly affect the housing stock. However, the impact of key actions external to the housing sector – particularly decarbonisation of energy supply – should not be under-emphasised. To date, emissions from the housing sector are estimated to have reduced by more than 40% from baseline 1990 levels. Three quarters of this improvement comes from cleaner primary energy supply (from changes to the mains gas and mains electricity grid) rather than changes to the housing stock itself.

The degree to which energy supply continues to decarbonise will significantly affect decarbonisation of the housing stock, and could influence the selection and effectiveness of dwelling-based retrofit actions. For this reason, it was deemed necessary to consider decarbonisation of energy supply within this piece of work. Three distinct energy supply scenarios were allowed to influence the models, to explore the impact of potential future changes to energy supply on decarbonisation of the existing housing stock, as follows:

Scenario 1 – minor future improvements to the national grid (40% clean energy supply)

Scenario 2 – significant future improvements to the national grid (60% clean energy supply)

Scenario 3 – transformational change to the national grid (80% clean energy supply).

The resulting discussion established the significance of each of the three energy supply scenarios in informing the development of a route map towards decarbonisation, in the context of current uncertainty around future changes to clean energy supply. Results are observed at the scale of individual dwelling archetypes (subsection 5.1), and in terms of the Welsh housing stock as a whole (subsection 5.2):

### 5.1 Findings: the dwelling archetypes

The Stage 1 scoping review suggests that there is considerable scope to develop appropriate retrofit strategies for the Welsh housing stock by employing actions that are well understood, and skills and products that are widely available.

Retrofit actions affecting dwelling fabric are the most thoroughly understood. The effectiveness of renewables and systems-based actions is less well understood, being more influenced by innovation and emerging technologies. The influence of people is the least understood aspect of retrofit, and introduces the greatest level of uncertainty around effectiveness, making future work around lifestyle choices and behaviour change particularly important.

The physical size and shape of a dwelling are not necessarily factors that change the approach taken to retrofit, apart from purpose built flats which are prone to overheating (see below). However, the physical size and shape of a dwelling do have considerable impact on capital cost and energy costs.

The selection of ‘appropriate’ retrofit actions is more likely to be informed by the current condition and character of the dwelling and its surrounding neighbourhood, by prior retrofit actions, and to a certain extent by the personal choice of the occupant or owner.

The predicted reduction in carbon emissions resulting from the retrofit of each dwelling archetype is highly dependent on the decarbonisation of energy supply, as described in table 3, below [8].

**Table 3.** Reduction in carbon emissions achieved by retrofit of the dwelling archetypes, for four retrofit strategies and three energy supply scenarios

<b>Retrofit strategy:</b>	<b>Carbon reduction by energy supply scenario:</b>		
	1. 40% clean energy	2. 60% clean energy	3. 80% clean energy
<b>Heritage</b>	58-66%	78-83%	100%+
<b>Good practice</b>	64-76%	81-87%	100%+
<b>Best practice</b>	83-89%	92-95%	100%+
<b>Rural</b>	86-96%	93-98%	100%+

After retrofit, 86% of the housing stock are predicted to experience an acceptable risk of overheating (a slight to medium risk, during peak summer months only). 7% of dwellings (mid terraced houses built 1965-1990) are likely to experience an elevated risk of overheating, which would need to be addressed (e.g. through improved ventilation or cooling). 7% of homes (flats built post 1965) would experience a serious increase in overheating (severe risk throughout peak summer months). This would need to be dealt with through adoption of an appropriate retrofit strategy, such as electric heating / cooling via a heat pump or air conditioning package.

Baseline capital costs are predictable for the four retrofit narratives, as described by the ranges below. Low costs are consistently for older, smaller mid terraced properties and high costs are for older, larger detached dwellings, as follows:

Good practice narrative	£17k to £32k
Best practice narrative	£33.5k to £63.3k
Heritage narrative	£10.8k to £25.5k
Rural narrative	£39.4k to £66.8k

The detailed specification of individual retrofit actions can have a considerable further impact on capital cost – particularly decisions around the use of materials or products that are ethically sourced, environmentally sustainable or have related health benefits.

For all narratives other than ‘rural’, *annual energy costs are predicted to rise considerably when strategies focussing on cleaner energy supply and retrofit of heating systems are employed.* (The ‘rural’ narrative predicts high existing energy costs by assuming heating is via Economy 7.) The increase in energy costs for the ‘best practice’ narrative are as follows:

Scenario 1 (which assumes no increase in fuel tariff) average increase 47% (26% to 59%)

Scenario 2 (which assumes a 50% increase in fuel tariff) average increase 120% (89 to 138%)

It is therefore reasonable to suppose that strategies focusing on cleaner energy supply and retrofit of heating systems will impact negatively on fuel bills for occupants. In contrast, when a holistic retrofit strategy is implemented, the percentage *reduction* in energy costs compared to current energy costs are:

Good practice narrative average of 33% (14 to 49%)

Best practice narrative average of 29% (20 to 42%)

Heritage narrative	average of 71% (58 to 78%)
Rural narrative	average of 11% (1 to 28%)

In the likely event that the costs associated with cleaner energy supply are passed on to households, there could be considerable increases in energy costs for residents, and therefore in fuel poverty. A low level of dwelling fabric retrofit will leave occupants highly vulnerable to future changes in fuel tariffs.

### 5.2 Findings: the Welsh housing stock as a whole

To model the housing stock as a whole in 2050, some assumptions were made. It was assumed that 15% of homes must be retrofitted to the ‘heritage’ standard because their retrofit is constrained by character (typically these would be listed buildings or located in a conservation area). It was assumed that 10% of homes must be retrofitted to the ‘rural’ narrative because they are situated in off-grid locations. It was assumed that the social housing and private rented sectors (30% of all housing) will be retrofitted to ‘best practice’ because housing standards provide a mechanism for enforcing holistic retrofit. It was also assumed that a further 15% of the stock, deemed to be in fuel poverty, will be retrofitted to ‘best practice’, to mitigate against the real risk that decarbonisation increases fuel poverty.

Initially, no assumptions were made regarding the remaining 30% of the housing stock (owner occupied homes, which do not currently have a mechanism for enforcing holistic retrofit). However, the research clearly indicated that unless clean energy supply goes considerably beyond 60%, carbon emissions can only be reduced beyond 90% if all homes are improved to the same standard:

**Table 4.** Assumptions made regarding retrofit strategy adopted by housing sector

Housing sector	% of stock	Narrative	SAP equivalent
Older protected homes	15%	Heritage	71
Off-grid homes	10%	Rural	90
Social housing + PRS	30%	Best practice	90
Fuel poor households	15%	Best practice	90
Remainder (owner occupied)	30%	Best practice	90

The results of modelling the housing stock as a whole in this way are as follows:

- Under scenario 1 (40% clean energy supply) it is not currently tenable for the existing housing stock to achieve >90% reduction in carbon emissions using established retrofit practice.
- Under scenario 2 (60% clean energy supply) >90% reduction in carbon emissions is only achieved when the entire existing housing stock (excepting 15% assumed to be older protected homes) is retrofitted to SAP90 or higher, with a transition to electricity as a source of heat (i.e. best practice or rural narratives).
- Under Scenario 3 (80% clean energy supply) target levels of decarbonisation are achieved through improvements in energy supply and services alone. However, fabric-based retrofit remains an important part of any decarbonisation strategy. It is critical that fabric-based retrofit is employed to reduce demand in primary energy use (as heating systems, hot water supply and transportation all transition to electricity as a primary energy source) and to minimise increases in fuel bills for occupants, and a consequent increase in fuel poverty.

## 6. Conclusions: key recommendations drawn from this research

Cleaner primary energy supply from the national grid is an essential part of any decarbonisation route map, and cannot be ignored. UK Government must be lobbied to ensure that energy supplied by the national grid exceeds 60% clean energy by 2050. Smaller scale generation of clean energy at a local or regional level must also be encouraged.

Cleaner primary energy supply is likely to increase fuel tariffs. Action must be taken to reduce household energy use and monitor future trends in fuel poverty, to protect vulnerable households and ensure that a consequence of cleaner energy supply is not an acute increase in fuel poverty.



Dwelling retrofit strategies that upgrade heating systems must also uplift dwelling fabric to an acceptable standard, to diminish increases in energy costs and fuel poverty.

There should be no distinction between standards for retrofit and newbuild, which are confusing and divisive. Similarly, there should be no distinction between standards based on tenure or housing type.

Some housing has retrofit constraints, notably pre-1919 housing with an established character or identity that would be diminished by extensive retrofit of the physical fabric. However the justification for such ‘acceptable fails’ must be carefully defined, so as not to jeopardise decarbonisation targets.

All other housing must be retrofitted beyond SAP90, which equates to current Building Regulations. The most straightforward way to achieve this currently is to insist all housing targets an EPC A rating.

Phased targets for retrofit of the entire housing stock (in line with carbon budgets) may appear to offer stepping stones for decarbonisation. However, retrofit of most fabric-based actions will be more cost effective if only undertaken once. Other options, such as boiler replacement, are likely to be undertaken more than once before 2050. There is a risk that phased targets will diminish, or obviate, the benefit of work carried out in early phases. In any case, actions that avoid lock-in should be utilised, and economies of scale should be explored.

Prescriptive retrofit approaches can limit opportunities for sensitive retrofit and reduce effectiveness.

To meet stringent decarbonisation targets, retrofit actions must overcome the performance gap (i.e. the results should be measured as delivered, not as predicted). A skilled, trained supply chain is needed to ensure that retrofit is appropriately conceived and properly implemented.

Retrofit standards are easier to enforce for social housing and the PRS sectors. Work must be undertaken exploring how to initiate this level of retrofit in the owner occupied sector. Point of sale represents an opportunity to drive new performance standards.

The impact of people on retrofit remains the least understood part of the process, and the one most likely to impact (positively or negatively) on the effectiveness of any retrofit strategies. Evidence indicates that occupants must be included in the retrofit process, and understand the retrofit actions being undertaken, if the anticipated carbon savings are to be realised.

A flexible approach that pushes all housing to achieve appropriate standards by 2050 is the only way to anticipate achieving >90% reductions in carbon emissions under assumed energy supply scenarios.

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