Challenges to achieving low carbon domestic retrofit and its effect on UK employment

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Abstract
In order for the United Kingdom (UK) to meet its overall climate change targets a reduction in domestic carbon emissions of at least 80 % by 2050 is required. The achievement of this goal necessitates a significant retrofit of the oldest housing stock in Europe. Completing this task will, therefore, present significant technical and economic challenges as well as economic opportunities. These opportunities include but are not limited to job creation needed for the performance of the retrofit.

This paper explores the major employment issues around retrofitting the UK housing stock, the likely broader economic impacts, and the policy requirements of performing large scale retrofit. In particular, it contrasts the rate of retrofit required to the capacity of the existing industry to both do the work and to train new workers. The paper also explores the implied decline in fossil fuel consumption and the increasing role of microgeneration within the wider UK energy sector.

Current research in other European countries has suggested that the net result of these conflicting trends will be a small net increase in jobs, as the labour-intensive sectors of construction and renewable energy grow at the expense of a decline in employment in the less labour intensive fossil fuel industries. However, UK has a number of unique characteristics, which may cause divergence from other European countries, such as the age of the housing stock and hence the complexity of retrofitting; an energy system highly dependent on fossil fuels; and a cold and damp climate.

Using emerging findings from modelling of the UKs housing stock, the key employment challenges for successful achieving of retrofit targets are highlighted, and possible solutions are discussed.

Introduction
Domestic emissions account for approximately one-third of the United Kingdom's (UK) total greenhouse gas emissions, with another third from transport and the remaining third from other sources. Thus, low energy and low carbon retrofit of the existing UK's housing stock is an essential part for the UK to meet its climate obligations. Within the UK, residential buildings are often considered to be an easier target for decarbonisation than other sectors such as road transport. While this assumption has elements of truth, as it is technically possible to retrofit dwellings to achieve low or even zero carbon emissions, there are nevertheless many technical and economic challenges to overcome if emissions are to be reduced by 80% or more by 2050 (Stafford, Gorse, & Shao, 2011).

Previous literature considering the economic effects of investment in energy efficiency and renewable energy suggest reasons for optimism (UKERC, 2014; Wei, Patadia, & Kammen, 2010). Substituting low labour intensity fossil fuel generation with higher labour intensity retrofit work, while simultaneously reducing overall energy consumption is expected to have a net positive effect on employment while reducing household energy costs. Energy efficiency measures typically have a higher capital cost, but then repay in small increments though the reduced energy bills. Much of the cost of domestic energy efficiency is the labour cost of installation, a task that cannot be easily automated or outsourced. The implication is that the UK's construction industry over the next 33 years must successfully identify these measures, create training programmes, and train new workers to take the installation of these measure from a niche activity to a mainstream business.

This paper is an early part of a two-year project 'Governance of Low-carbon Innovation for Domestic Energy Retrofits' (GLIDER) attempting to address the practical changes to achieving decarbonisation of the UK housing stock. As such, this paper presents a proposed methodology and emerging findings intended to highlight the employment effects of retrofitting the UK housing stock. The paper outlines three broad stages of research: Firstly, understanding the nature of the retrofit work required within the UK context, for which emerging findings are presented; secondly, the labour and economic requirements needed to undertake the work; finally, the effects on the broader economy on successfully achieving the retrofit of the UK housing stock. [1]

Literature Review

There is an emerging consensus in the literature that energy efficiency has a net positive effect on employment while reducing energy costs for households and reducing overall carbon emissions (Lehmann et al., 2016; Michaels & Murphy, 2009; Pollin, 2009; UKERC, 2014). While economic and energy modelling within these studies can be considered current 'best practice', the models of the housing stock and retrofitting can be comparatively simple.

Typically, a package of potential retrofit measures is considered, and the cost to retrofit calculated. While this is a reasonable approach to take if the goal is to produce an economic model, it glosses over practical issues of performing retrofit such as:

- Whether sufficient skilled workers exist to do the retrofit work;
- Whether training capacity exists to train additional workers required;
- How one retrofit measure may preclude or complement another measure, e.g. limited roof space cannot be used by both solar thermal and Photovoltaic (PV) panels;
- The conflicts between adoption of measures appropriate for short term moderate energy efficiency (e.g. a new gas boiler) and those suitable for long term deep carbon savings (heat pump).

These limitations may be exacerbated when comparing conclusion drawn from other countries and attempting to apply them to the UK's housing stock with its own and its unique retrofit challenges.

1.As this paper is concerned with the employment effects of a successful retrofit programme, it assumes that an 80 % reduction greenhouse gas emissions must be achieved by 2050, as compared to 1990 levels. This assumption allows a focus on the rate of retrofit required to achieve climate targets in comparison to historical rates. It should be noted that it is not certain that such an ambitious retrofit will or even can be achieved.

THE UK HOUSING STOCK IN CONTEXT

The UK housing stock is made up of approximately 28 million dwellings. The vast majority (90 %) of these dwellings are single family detached, semi-detached, or terraced houses (Cooper & Palmer, 2011). The UKs dwellings are small by European standards and have low occupation rates (Morgan & Cruickshank, 2014). The housing stock is also old by international standards and has comparatively poor energy efficiency (DCLG, 2013; Dowson, Poole, Harrison, & Susman, 2012; Economidou et al., 2011).

In 2015, the domestic sector was responsible for 29 % of the UK's energy consumption (BEIS, 2016). Domestic energy consumption increases steadily since the 1970s but has declined in recent years to 80 % of its 2004 peak, mainly due to a decrease in natural gas consumption.

Figure 1 shows domestic carbon emissions per dwelling by fuel type (left axis, area chart) and total domestic energy consumption for heating and electricity (right axis, lines). The history of UK domestic energy use can be divided into two phases; from 1970 – 2004, both electricity and heating energy use rose, while carbon emissions fell driven by the substitution of coal with natural gas as a source of heating and in the generation of electricity. These reductions in emissions have partly been a side benefit of the 'dash for gas' that occurred when natural gas was discovered in the North Sea. This transition facilitated the uptake of central heating, which improved thermal comfort and was clean in comparison with coal fires. Secondly, since 2004 electricity consumption has declined gradually while heating energy use has declined more rapidly, emissions have continued to decline roughly in line with consumption.

In parallel, the contribution of energy efficiency to emissions reduction was mainly seen in terms of improving the thermal performance of building fabric (primarily loft and cavity wall insulation) and increased efficiency of heating systems (mostly boilers) (Shorrock, 2003).

In more recent years the UK government has promoted the uptake of specific low carbon measures such as loft insulation or rooftop solar panels, with the explicit intention of reducing carbon emissions and energy bills. That being said, the majority (90 %) of dwellings in the UK are heated by gas powered central heating, and nearly all dwellings are supplied with mains electricity. Domestic energy use is dominated by space heating (61 %) and to lesser degree water heating (18 %) (Palmer & Cooper, 2013). Energy use by appliances has risen gradually since the 1970s but still only make a small fraction of total energy consumption (14 %), which leads to the presentation of some of the challenges that exist within the UK housing stock context.

CHALLENGES TO ACHIEVING LOW CARBON DOMESTIC RETROFIT IN THE UK

The structural problems with the UK construction are widely acknowledged, the 2016 Farmer Review of the UK Construction Labour Model noted that "there appears to be a general acceptance of failure and underperformance both by industry itself but also begrudgingly by clients" (Farmer, 2016). Although Farmer focuses on the new build industry, of relevance to this paper, is the fragmented nature of the construction industry and the extremely low levels of training, particularly in the small businesses of the housing sector (Clarke & Wall, 2000).

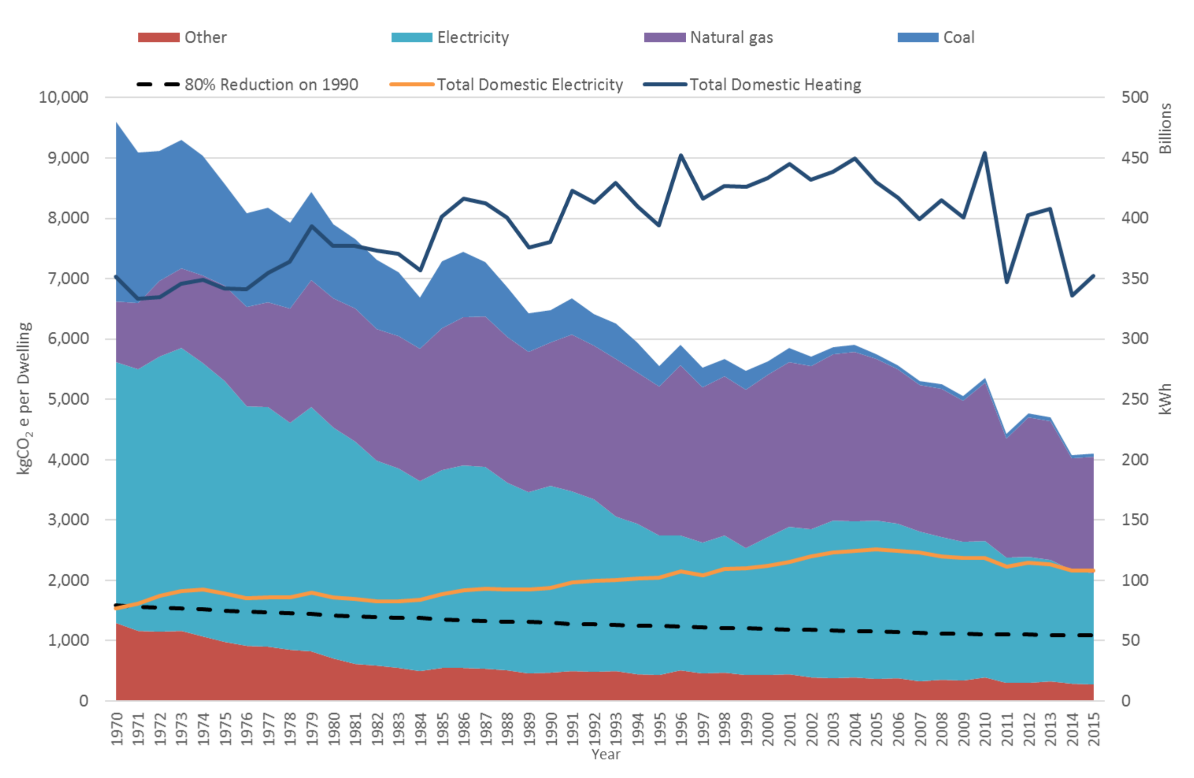

Figure 1. UK Domestic Carbon emissions by fuel source, derived from DUKES (BEIS, 2016).

These limitations suggest the industry may be unable to deliver the rate of retrofitting implied by previous economic modelling without radical improvements to vocational education and training.

To compound the existing structural problems of the construction industry, the domestic retrofit sector has been historically very sensitive to the changes in government policy, such as the recent cuts in funding for energy efficiency and renewable energy (Pitt, 2014; Vaughan, 2016).

Indeed, housing energy policy is at something of a crossroads, as the historical programmes designed around relatively cheap and quick measures approach saturation, leaving a large technical potential, which government policy has so far failed to mobilise (Mallaburn & Eyre, 2014)

EMPLOYMENT EFFECTS IN UK ENERGY RETROFITTING CONTEXT

There has been a range of studies considering the employment effects of energy efficiency and/renewable generation. Of particular relevance to this paper are the 2014 UK Energy Research Centre (UKERC) review of Low Carbon Jobs (UKERC, 2014) and the Cambridge Econometrics report 'Building the Future: The economic and fiscal impacts of making homes energy efficient' (Washan, Stenning, & Goodman, 2014).

The UKERC report reviewed a total of 84 studies across the peer-reviewed and non-peer review literature. It concluded that there was reasonable evidence for net job creation from renewable energy and energy efficiency investment. However, the overall effect was sensitive to the structure of the economy under consideration. This suggests that different results may be obtained in the various countries and at different points in the economic cycle.

The Cambridge Econometric report focused in more detail on the economic and fiscal effects of upgrading all dwellings in the UK to Energy Performance Certificate (EPC) Band C by 2035. Where Band A is most efficient, and Band G is least efficient. The report found that 108,000 net jobs would be created between 2020 and 2030, from £126 Billion of public and private investment between 2015 and 2035. Taken as a whole, the literature suggests that there is a small net positive effect on jobs largely due to the more labour intensive nature of construction in comparison to the fossils fuel sector. There is, however, variation in the estimates based on the underlying assumptions and countries or regions under consideration.

SUMMARY OF ASSUMPTIONS

In summary, an outline of the main methods for reducing the UK domestic emissions is:

1. Improve the thermal performance of the building, so that less heating is required;
2. Improve the efficiency of heating systems, so that less fuel is required;
3. Substitute heating systems with low-carbon alternatives;
4. Reduce carbon intensity of grid electricity;
5. Substitute grid electricity with low carbon onsite electricity generation;
6. Behaviour change, which reduces energy consumption.

The literature is largely in agreement that a single solution approach is unlikely to be effective and that a mixture of technologies is required (Stafford et al., 2011). As this paper describes emerging findings a full range of possible scenarios has not yet been explored, thus the following simplifying assumptions have been made:

1. Only the retrofit of existing dwellings is considered, new build dwellings have been excluded from the analysis. Previous research has suggested that around 80 % of the 2050 UK housing stock has already been constructed and that the rate of demolition and replacement of dwellings is low (Power, 2010).
2. No net behaviour change, residents neither increase or decrease their demand for warmth or electricity.
3. Grid electricity is decarbonised, and that supply is not limited.
4. Carbon reductions are achieved through a mix of insulation, increased efficiency, and micro-generation.
5. The target of 80 % carbon reductions is reached by 2050.
6. No significant technical innovation or change in costs.

These assumptions are by design constraining to limit the scope of this paper, expanding on some of these constraints will be the subject of future research.

Method

This section outlines the three stages of the proposed methodology. Firstly, developing an improved understanding of the retrofit requirements of the UK housing stock; Secondly, translating retrofit requirements into labour and economic activity; Finally, modelling the broader economic effects of the activity.

RETROFIT REQUIRED TO ARCHIVE CARBON TARGETS

Previous research has shown that while significant emission reductions can be achieved through the adoption of a collection of individual measures, reductions of 80 % or more require a joined up whole house approach (Jones, Lannon, & Patterson, 2013). The diversity of dwellings in the UK means that single approach will not be suitable. Therefore, a selection of archetypal dwellings is required which can be considered similar from a retrofit perspective.

The purpose of the archetypes is to identify the different retrofit approaches that are required and their relative proportions in the housing stock. This method differs from previous attempts to produce housing archetypes, which have been used for energy modelling. In this paper, archetypes have similar retrofit options but may have differing performance gains from adopting a specific option (Washan et al., 2014).

The archetypes were constructed using data from four years of the English Housing Survey (EHS) (2010–2013). Each dwelling in the EHS has been characterised by five components as shown in Table 1. Archetypes have been produced for each component, and are described below. For each archetype, the retrofit pathway is briefly summarised. Although the EHS only covers housing within England, not the UK as a whole, as England contains 85 % of the housing stock, it is largely representative of the UK.

Adoption Curves

Use the prevalence of different archetypes it is possible to calculate the total number of installations of a retrofit measure that will need to be completed by 2050. By fitting an S-curve to the adoption of each measure and taking account of the current adoption, it is possible to calculate the number of new installations per year for each retrofit measure.

$$A = \frac{L}{1 + e^{-k(x-x_0)}} \quad (1)$$

Equation 1: S-Curve Equation, where
L Maximum potential adoption
k curve steepness
x year
x_0 midpoint of the curve.

Table 1. Component Archetypes and retrofit pathways.

Architype and prevalence		Retrofit pathway
R1. Pitched Roof	72 %	Loft insulation is installed above the ceiling to a depth of 300 mm. Solar panels are installed depending on suitability.
R2. Pitched Roof with room in roof space	7 %	Insulation is installed between the rafters. Solar panels are installed depending on suitability.
R3. Flat Roof	6 %	Flat roof insulation is installed. Solar panels are installed depending on suitability.
R4. No roof	14 %	Flats and dwellings that do not have a roof directly above
W1. Masonry Cavity Walls	73 %	The cavity is insulated, some dwellings also have external wall insulation fitted.
W2. Solid Masonry Walls	20 %	50/50 mix of internal and external wall insulation
F1. Solid concrete floors	79 %	a combination of insulation approaches
F2. Timber suspended floors	29 %	Floors are insulated
E1. A conventional boiler mains gas boiler, providing both hot water and central heating, using a hot water tank.	28 %	The boiler is upgraded to condensing boiler, solar water heater fitted, boiler ultimately replaced with a heat pump.
E2. A combination boiler, providing hot water and central heating without a hot water tank.	51 %	Boiler upgraded to condensing boiler, boiler replaced with heat pump
D1. Doors and Windows	100 %	Windows and doors are upgraded to post 2007 energy standards

The adoption of each retrofit measure was calculated using Equation 1 for each year from 2015 to 2050. Each S-curve was independently constructed reflecting the current adoption of the measure and the expected rate of replacement. For example, gas boilers have a relatively short lifespan, of around 12 years, and new boilers have to meet high energy performance standards. Therefore, the s-curve was adjusted to reach near complete adoption of high-efficiency boilers by 2030. In contrast, air source heat pumps are largely unknown in the UK. Thus adoption is modelled to be low in 2030.

For some retrofit measures, with comparatively short life spans, it will be necessary for them to be repaired or replaced before 2050. Expected lifespans can be factored into the number of installations per year. Replacement of existing retrofit measures will become increasingly important in the 2040s, as there will be a shrinking number of dwellings that have not yet been retrofitted. If correctly timed the decline in new installations can be matched an increase in repair and replacement. If the adoption is poorly timed large variations in work over time could be difficult for the industry to adapt to and may result in a failure to meet 2050 climate targets.

LABOUR AND ECONOMIC REQUIREMENTS TO UNDERTAKE THE RETROFIT WORK

Having identified the volume and rate of retrofitting work required for different measures, the second stage is to convert this information into hours of work, and costs. Typical economic modelling calculates costs and then using conversion factors of full-time equivalent jobs per million pounds invested. However, such models make assumptions that labour is substitutable between sectors and that education and training for new skills can similarly be achieved without constraint (UKERC, 2014). We seek an approach, which estimates the jobs potential but also estimates the skills requirement.

By gathering data on the time and skill requirements of different retrofit task an estimate of how many workers are required to achieve the rate of retrofits outlined in the previous section. In turn, this can be used to estimate the volume of training required per year. These rates can then be compared with the current capabilities of the UK construction industry, and allow an evaluation of any capability gap.

EFFECTS ON THE BROADER ECONOMY

The effect of retrofit on the UK economy will be calculated using a multi-regional Input Output (MRIO) model (Owen et al., 2017). This model is used to produce the official Consumption Based Accounts (CBA) for the UK, thus a credible model of the UK economy. The MRIO can evaluate changes in the economy, labour market, and the resulting effect on carbon emissions. This allows the net effects of a retrofit programme to be assessed and to identify if it genuinely has reduced carbon emissions or merely displaced them. The UK MRIO is based on the 106 sectors of the Supply and Use tables produced annually by the Office of National Statistics, and the International Energy Agency (IEA), which annual energy data by country.

Preliminary Results

This section discusses preliminary findings from the first and second stages of the methodology, i.e.: formulating the retrofit requirements using housing archetypes and translating those requirements into labour output and economic activity. Each section concerns a different part of the dwelling, (roof, wall, and floor) and shows a graph of the model number of installations per year for different retrofit measures. For some retrofit measures, historical rates of installation are available from the Energy Company Obligation (ECO) and its predecessor Carbon Emissions Reduction Targets (CERT), or the Microgeneration Certification Scheme, where available these provided as context to the modelled outputs.

ROOF & LOFT MEASURES

Although most dwellings have some loft insulation, typically 100 – 150 mm, relatively few have the full 300 mm of insulation recommended by government policies. Base on simple S-curves, the installation rate of loft insulation would need to increase until the late 2020s. Recent changes in government policy have resulted in a sharp decline in the number of dwellings that are being insulated as shown in Figure 2.

This suggests that the installation capacity already exists and that, as long as the installers fit the 300 mm of insulation, lofts will be fully insulated by 2050. The second peak beginning in the 2040s represents insulation reaching the end of its life

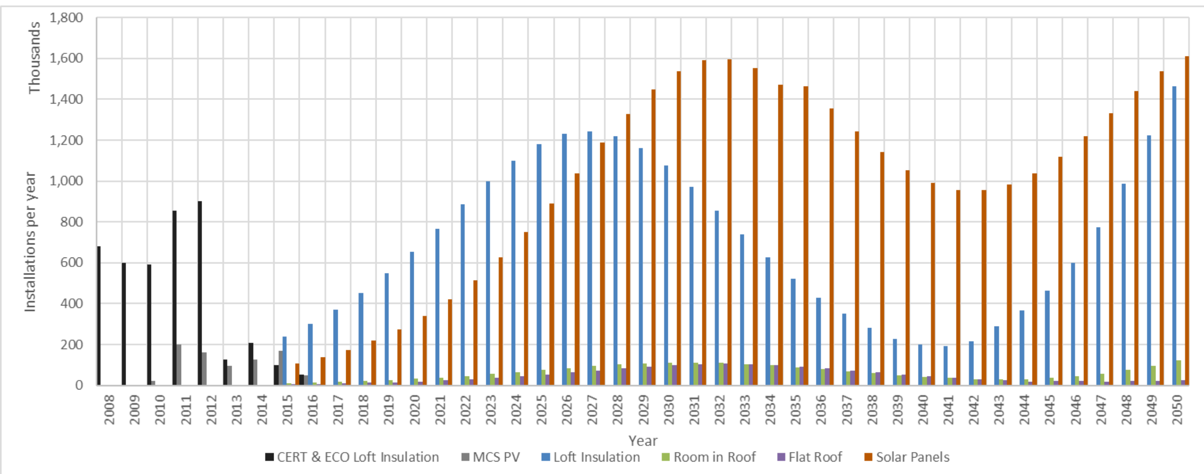

Figure 2. Projected Adoption of Roof Measures.

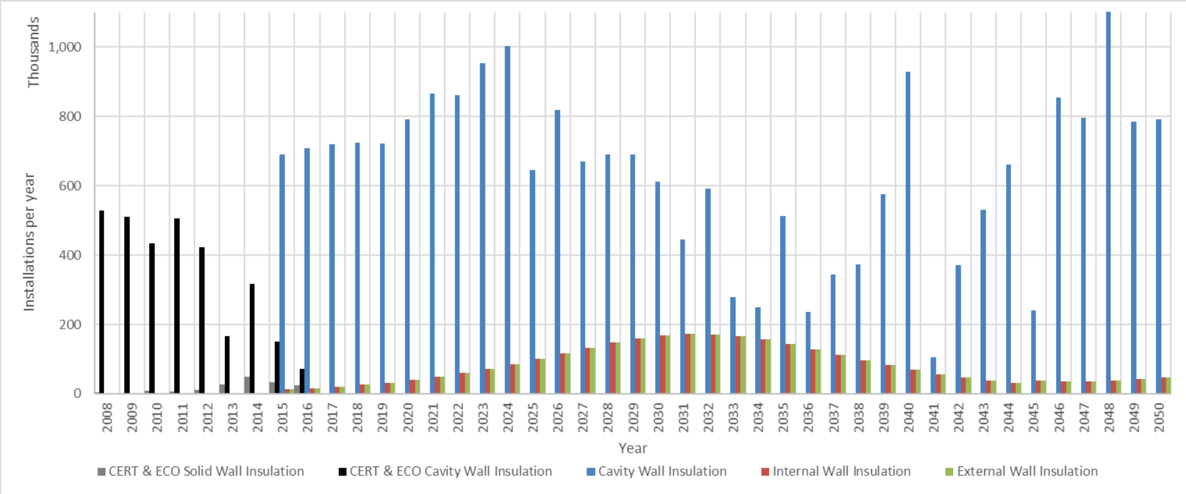

Figure 3. Projected wall insulation installations.

and needing replacement. It may well be possible for installers to maintain a steady rate of around 700,000 lofts per year to smooth out the peaks and troughs indicated by the models. In contrast, the rate of insulation of flat roof and dwelling with a room within the roof space are low, as they make up a comparatively small proportion of the housing stock.

The EHS suggests that most dwellings have at least some area of the roof suitable for solar panels, in terms of pitch, orientation, and the absence of shading. Thus, it has been assumed that by 2050 suitable dwellings will have solar panels installed. The model in Figure 2 suggests that there would need to be a significant increase in the rate of installation from the current rate of 170,000 installations per year (2015) to a peak of 1.6 million installations per year (2032) to complete the rollout of PV panels by 2050. The shorter lifespan of PV panels (20 years) provides more overlap between the decline in new installations and the increase in panels needing replacement. A fivefold increase in the domestic PV market, to an average of 1 million installations per year, would probably require support from government policy and further reductions in the cost of PV panels.

Typical domestic PV systems in the UK are currently around 4 kWh/day with a typical load factor of 9.7 % (Hemingway, 2013). This would suggest that the housing stock could supply 38 TWh of electricity per year by 2050, around 8% of current domestic energy demand, or a third of current domestic electricity demand. While this is not an insignificant contribution to the decarbonisation of the housing stock, it highlights that the typical British home does not have the capacity to be net energy generator. Therefore, it is likely that domestic buildings will still be a major consumer of grid electricity in 2050 thus highlighting a potential challenge to achieving low carbon domestic retrofit by the set deadlines.

WALLS

Walls constitute a significant proportion of total heat loss from dwellings, thus have historically been a primary target of insulation. Masonry cavity walled dwellings make up most the housing stock, of which most now have cavity wall insulation. Figure 3 illustrates a model of the installations per year of cavity wall insulation, internal wall insulation and external wall insulation.

Historic cavity insulation rates of 400,000–500,000 installations per year are comparable with the average required rate of 650,000 installations per year for the retrofit to be completed within the designated time parameters. However, the recent government cuts have seen a decline in dwellings insulated rather than the required increase needed to make up the difference to 650,000.

After 2025, the model as shown in Figure 3 is dominated by the replacement of older cavity wall insulation rather than new installation. Additionally, data on the age of cavity wall insulation is limited, which also may explain the erratic nature of the forecasts from 2030–2050 (Cooper & Palmer, 2011). In practice, peaks are likely to be evened out as delay or accelerate maintenance due to personal circumstances and natural variation in the product lifespans. However, it this stage of the analysis it is useful to highlight the high levels of uncertainty that exist in the future of retrofitting, which can be hidden within economic models.

FLOOR ARCHETYPES

The next archetypes to discuss are the floor archetypes. There are two major types of construction that exist in the UK: suspended timber floors as seen mostly in older dwellings and solid concrete floors as seen in more recent buildings. Figure 4 depicts the floor installation projections for both types of floors from 2008 to 2050.

There is very limited information available about the prevalence of different floor constructions within the UK housing stock, or the uptake of floor insulation. Anecdotally, insulation levels are very low, and so have been assumed to be zero for the purposes of the model. The uptake of underfloor insulation, as shown in Figure 4 is highly speculative. The mass insulation of suspended timber floors is conceivable, as the process is somewhat similar to loft insulation with the added complication of raising the floor boards. In contrast, insulating solid floors either requires laying insulation on top of the concrete slab and raising floor levels or digging out the slab and backfilling with insulation; either option is expensive and disruptive. Underfloor insulation highlights another example of the possible disconnect between economic models and retrofit realities. In the short term, there are cheaper and or easier ways to reduce domestic energy use, however as the performance of walls, windows, and roofs improves the poor performance of floors becomes increasingly important. In the short term, it makes economic sense to delay under floor insulation in favour or cheaper and easier measures, but a delay in uptake makes completing the retrofit of all dwellings by 2050 infeasible.

DOORS AND WINDOWS ARCHETYPES

The following archetypes are those of the doors and windows. For simplicity, this analysis of windows excludes the buildings, which due to conservation rules have restrictions on the types of windows that can be fitted. The UK has a small minority (1.5–2 million) of single glazed heritage properties, where modern double glazing is not permitted (Bottrill, 2005).

Unlike some other aspects of retrofit, doors and windows are more like a consumer product, as they are usually manufactured off site to high and consistent standards. Since 2007, new windows have had energy performance ratings from G to A++, with current building regulations mandating a minimum of C rating, although many manufacturers are producing A rated or better. As doors and windows installation is similar when discussing retrofit in relation to both design and skill required, and the typical dwelling has many more windows than doors, this section will particularly focus on window installations in order to simplify the task. Two models are considered for the replacement of windows as illustrated in Figure 5.

The two models are considered in Figure 5. First, an S-curve used with previous archetypes and second, a replacement based on a typical 20-year lifespan (Dowson et al., 2012). This replacement rate is reflected in the EHS with over 78 % of windows being less than 20 years old, and an average age of 17 years. Each method produces broadly similar overall estimates for the total number of installations up to 2050 (40 million compared to 37 million). However, the timing of the installation varies.

The replacement method shows a more constant rate of installations with a few peaks but relatively steady. The peaked nature of the scenario is due to the low quality of the data that exists currently on the age of current windows in the EHS, which often only provide an estimate of the windows age.

The reality is likely to be between these two models. Homeowners will continue to replace windows and doors when they are in need of replacement, and the energy efficiency of replacement windows gradually rises as regulated standards increase. This raises interesting policy options; if the goal is to ensure all dwellings have high-efficiency windows by 2050, then it may be possible to simply wait for a natural replacement. As long as the minimum standard for new windows gradually rises so that a new window in 2030 is efficient as all windows need to be in

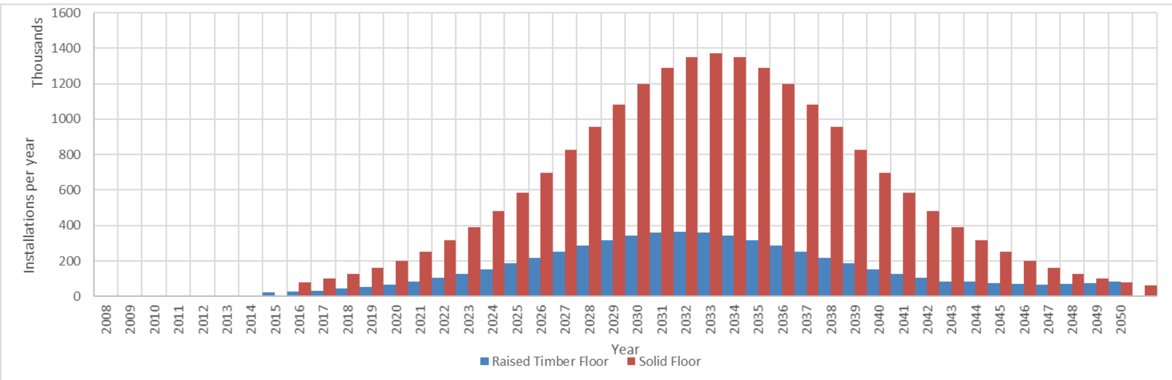

Figure 4. Floor Installations.

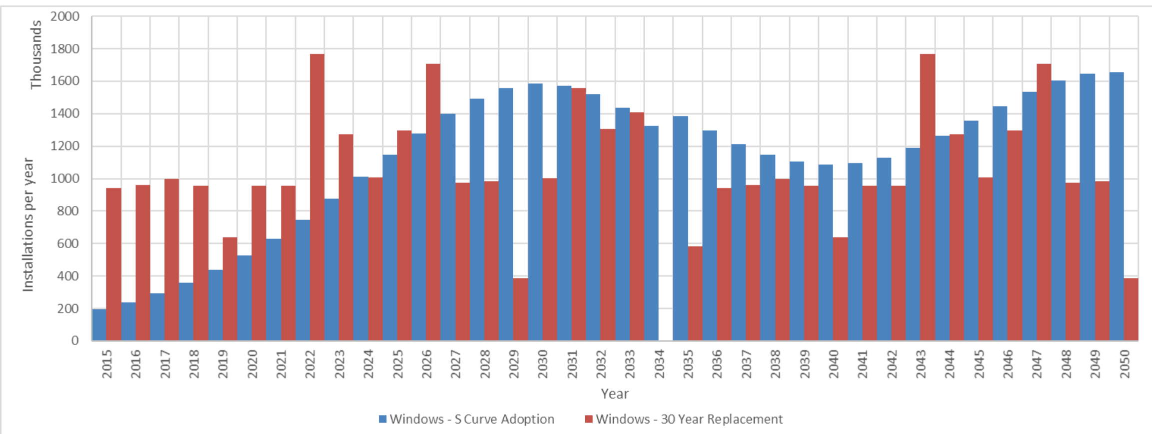

Figure 5. Windows Installations.

2050. However, if there is a need to improve the performance of windows more rapidly, perhaps to compensate for slower adoption of other retrofit measures, then minimum standards must be raised more quickly.

HEATING SYSTEMS

The final retrofitting aspect to discuss is the heating systems within domestic dwellings. As mentioned earlier, in the UK the majority (90 %) of dwellings are heated by gas powered central heating, and nearly all dwellings are supplied with mains electricity. Retrofitting the energy system then is an important step towards achieving low carbon homes. There is, however, far less certainly how heat and electricity will be supplied in the future.

Figure 6 illustrates the assumption within the model that in the short term, it has been assumed that the adoption of more efficient boiler gas boiler will continue. While in the long-term boilers are replaced with heat pumps and district heating systems, these are in line with the Government plans for renewable heat (DECC, 2013), but for simplicity have excluded biomass, biogas and solar thermal heating systems. Figure 6 shows a highly uneven overall rate of installation, which may be challenging for the retrofit industry to achieve.

OVERALL COSTS

By substituting average costs into the model, it is possible to make an approximation of the total annual cost of retrofitting, as shown in Figure 7. The model used a simple cost estimation approach, and as such, does not consider changes in cost over time or distinguish different costs for new and replacement installations. These costs are based on 2015 prices and do not take account of inflation or discounting. These improvements will be included in the future. It does, however, highlight that expenditure on retrofit will have to rise significantly and that the costs of retrofit in this scenario are dominated by windows, new heating systems, and photovoltaic panels.

The Office for National Statistics estimates that 14.94 jobs are created for each £1 million of output (ONS, 2010), suggesting that 380,000 gross new jobs would be required by 2036. This is a significant overestimate as for some retrofit measures, such as PV panels and windows, much of the cost is in the manufacture of the materials not in the installation. Manufacturing has far lower labour intensity. Further work is required to break down the costs and labour estimates per retrofit measure to better understand the true effect on employment.

Further Work

The follow-on work from this paper can be divided into three stages. Firstly, further refinement of the retrofit models, to consider both complimentary and conflicting interaction between different retrofit measures and expand the breadth of retrofit measures considered. Secondly, to understand the required number of workers to performed the modelled retrofit, the costs, and the reductions in energy demand and carbon emissions. Finally, using this new understanding as the basis of an economic model to establish the effects on the broader economy and whether the changes in underlying assumption effects the broader conclusions of domestic retrofits effect on the UK economy.

Conclusions

This paper has outlined a proposed methodology and emerging findings, to challenge implicit assumptions in the economic modelling of retrofit. The paper postulated that, by focusing on the rate of installation, it is possible to understand how much work and thus how many people will be required to perform a retrofit of the UK's housing stock. Furthermore, the paper postulated that the proposed method would provide more insight than traditional approaches to economic modelling.

The paper has shown that the required rate of installation for various retrofit measures differs significantly, both in overall magnitude and distribution between now and 2050. For some measures, an S-curve may be the most suitable model of adoption, whereas other measures are more likely to follow a linear adoption model. This is particularly true for measures, which are mealy replacing existing features such as boilers or windows.

Further work is required to refine the retrofitting model and to convert rate of installation to costs and employment estimates. Once completed these results can be contrasted with traditional economic models, this will allow the model's assumption to be tested and may provide insight into future policy requirements around the training of retrofit practitioners.

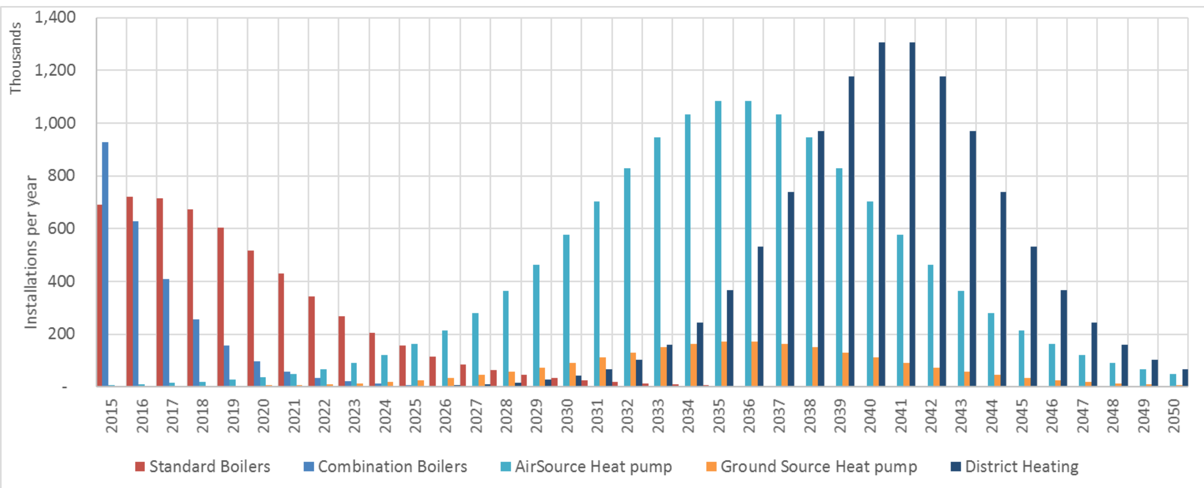

Figure 6. Heating Systems Installations.

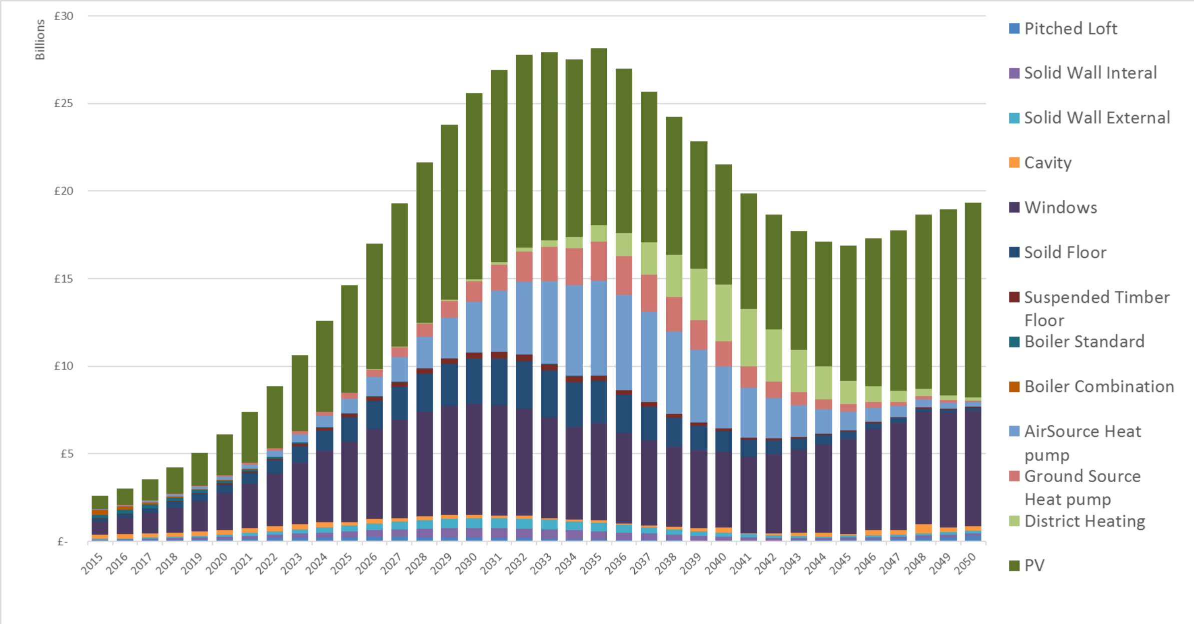

Figure 7. Total retrofitting capital costs, in 2015 GBP.

As this paper used simple models of technological adoption with several simplifying assumptions, it should not be used as a forecast of future retrofit work. It does, however, highlight the need for a long-term plan for domestic retrofit is the multiple technological changes required are going to be completed by 2050. The outlined further work will provide the necessary to formulate such a plan.

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