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Common Weal Policy

CARBON-FREE, POVERTY-FREE: HEATING OPTIONS FOR RURAL SCOTLAND

A policy paper for Calor by Common Weal, Glasgow Caledonian University, and the Energy Poverty Research initiative

Common Weal

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www.commonweal.scot
www.commonspace.scot
hello@common.scot

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The Energy Poverty Research initiative (EPRi)

The Energy Poverty Research initiative was founded in 2017 by Dr Keith Baker, Dr Ron Mould, and Scott Restrick, with the aim of establishing a Scottish Centre for Excellence in Energy Poverty Research. The initiative is currently funded privately by its members and frequently collaborates with Common Weal. As academics and practitioners, we share the view that in an energy rich nation it is not acceptable that such a large proportion of households suffer daily the deleterious effects of energy rationing, or that they are forced to manage debts just to maintain a reasonable modern standard of living. We believe we have a duty to continually question our understanding of this modern societal inequality, and the methods and approaches we take to identifying and tackling it.

www.energypovertyresearch.org

AUTHORS

Dr Keith Baker is a Researcher at the Built Environment Asset Management Centre, Glasgow Caledonian University, Co-founder of the Energy Poverty Research Initiative, and a member of Common Weal’s Energy Working Group.

Dr Ron Mould is a Co-founder of the Energy Poverty Research initiative and a member of Common Weal’s Energy Working Group.

Craig Dalzell is Head of Policy at Common Weal

Jonathan Shafi is Head of Campaigns at Common Weal

KEY POINTS

This report has been commissioned by Calor and forms a joint submission from Calor, Common Weal and the Energy Poverty Research Initiative to the Scottish Government's call for evidence in the future of low carbon heat for off-gas buildings.

Fuel poverty is not only worse in rural Scotland than in urban Scotland, it also has different characteristics. For example, in urban areas 92% of those classified as income-poor are not classified as fuel-poor while in rural areas only 8% of those classified as income poor *are not* also fuel poor – fuel poverty plays a much larger role in rural poverty than in urban poverty. While there are some differences on average between the housing stock in urban and rural areas (there are few rural dwellings in multiple occupation), by far the biggest driver of this fuel poverty is not being on the gas grid. In urban areas 92 per cent of properties are able to connect to the gas grid but 64% of rural houses do not have that option.

While rural fuel poverty has some link to many factors (income, education, health), by far the most significant correlation is with access (the physical distance from the gas grid and from public services). This makes clear that decarbonising heating in rural areas has different factors to decarbonising heating in urban areas but that the range of technologies available is much the same. Those is rural fuel poverty who will not be able to replace their old oil boiler will need affordable low-carbon alternatives. Policy responses need to accommodate this otherwise a large section of rural Scotland will remain on fossil fuels or be condemned to higher energy costs (electric heating is the easiest non-carbon heating source to install but is also more or less the most expensive). Unless a systematic approach is taken focusing on the long-term outcomes for rural households, the impacts will only exacerbate rural fuel poverty and increase inequality. It is the view of the report's authors that this is a likely outcome of the Scottish Government's current proposals.

There are a number of reasons for concern in the current approach. They rely heavily on the use of Energy Performance Certificates which have serious shortcomings which will particularly count against rural heating and so disincentivise development (more information on the problems with EPCs can be found in the Common Weal policy paper 'Energy Performance Certificates: An Alternative Approach'). Too much of the responsibility is being put on households or local authorities and too little national coordination is involved. And the current strategy inadequately addresses crucial issues such as solar thermal generation, inter-seasonal heat storage, the site-specific nature of technologies such as water-source heat recovery, and the benefits of developing sustainable fuel supply chains for district heating. Further evidence on the latter can be found in the Common Weal Policy paper 'Just Warmth:

Developing equitable and sustainable district heating systems in Scotland'.

The report therefore assesses strengths and weaknesses of all the possible low-carbon heating options. The findings are as follows:

- Electricity is cheap to install and familiar to users – but it is very expensive to run and ties household emissions to that of the electricity grid. Some emerging technologies such as infrared have some potential applications (particularly in solid stone-wall dwellings) but are probably not optimal for most housing.

- Household-mounted solar thermal is cheap to install, cheap to generate and highly flexible – but a standard installation will not meet 100 per cent of heating need (particularly in properties which share a roof) and would require the additional installation of heat storage or for changes in occupants' habits and behaviours. Large-array solar thermal has even more advantages than household-mounted, producing very cheap heating that can be stored and is capable of providing over half of heating requirement – but it requires a district heating system to distribute the heat.

- There are a variety of biogas and waste incineration options including anaerobic digestion of waste and the use of biomass to generate bioLPG. It has the advantage of being an easy, direct replacement for natural gas and oil but government support will be required to incentivise the development of domestic sources of bioLPG supply.

- Both ground-source and air-source heat pumps have a role to play but are site specific, have long repayment times and all require an additional heating source to top up the heat level (which usually involves non-renewable heating sources). Larger scale heat pumps attached to district heating schemes have much higher efficiency.

- Hydrogen can be used as a direct gas replacement but is very expensive to produce and large-scale deployment would almost certainly rely on carbon capture and storage (CCS) and would compete with other uses for hydrogen such as transport. (However, this is a better option for communities which have excess renewable electricity supplies, such as islands with limited capacity to export to the grid).

- Wood fuel biomass has significant scope to replace existing heat sources at a fairly competitive price, but its use in urban areas will be limited by pollution legislation and it would be imperative to ensure a reliable domestic supply chain for the fuel source.

The conclusion from this review of heating options is there will need to be a multiple-technology approach to decarbonising heat everywhere in Scotland with no single credible solution able to meet demand in any one location (and few households having the conditions which would enable a single renewable replacement technology). The efficiency of household-level heat pumps is overestimated (though large-scale heat recovery from flooded mineworks or waterways is much more efficient), hydrogen and electricity are too expensive for anything other than niche applications, biogases and various waste options would not be sufficient to meet demand alone and have supply-chain limitations, wood biomass is not suitable for urban areas (and requires a lot of space and coordinated supply chains), and solar thermal is very promising but is generally insufficient to meet one hundred percent of household heating demand (without additional thermal storage or changes in household behaviour). The conclusion here is that by far the best way to decarbonise energy is to use multiple technologies – but to get the most from them they must be used at scale. This requires a district heating system along the Danish model to distribute centrally-generated heat round households.

It is generally thought that district heating is not a viable option for rural areas. This is true for very remote properties, but in fact the cost for installing rural district heating is not substantially higher than urban district heating schemes. This is because, while the distances are greater, the necessary pipework is easier to install because access is easier. There is therefore no reason district heating cannot supply a solution to much of rural Scotland. However, there will remain properties and communities for which this is not an option - and that may be as high as 40 per cent of rural properties. In these cases, the solution is likely to be bioLPG. wood biogas or biomass boilers, potentially in combination with building-mounted solar thermal. Electric heating may be appropriate to some communities where there is excess local electricity generation from renewable schemes.

There are a number of worries about the implications, costs and scale of replacing existing heating sources. These are considered in some depth in the main report. The broad conclusion is that some disruption and cost is inevitable if Scotland is to meet targets for decarbonising heating but there is no particular reason to believe that the packages of measures proposed here is unviable.

To make this transition to a low-carbon heating solution for rural Scotland, a number of things will need to happen. First, the Scottish Government absolutely must take responsibility for a coordinated strategy to enable the transition. It must start ‘signalling’ the kinds of behaviours required, such as modelling the electricity grid capacity based on heating requirements, creating pressures to move to low-carbon heating in building regulations, banning new oil and coal boilers in the next few years, reforming Energy Performance Certificates so they no longer act against the interests of low-carbon heating, and ensuring that funding is available for the cost of transition, potentially through the Scottish National Investment Bank. These are all actions which are required for both rural and urban transitions, but they are particularly important for rural areas because of the risk of households being locked-in to expensive short-term solutions.

Common Weal has already published a number of reports on energy strategy and has set out a coordinated vision of where energy policy must go next. To deliver this it has been proposed that a National Energy Company and a Scottish Energy Development Agency be set up. Without these forms of coordinating body it is hard to see how Scotland can make a sufficiently swift progress to decarbonising heating such that it can meet its crucial carbon reduction targets – and to tackle fuel poverty in Scotland head-on

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1: INTRODUCTION

The Scottish Government's plans for decarbonising heat under the Scottish Energy Strategy (SES) centre around a combination of shifting households to renewable electric heating and developing low and zero carbon district heating systems (DHS) (Scottish Government, 2017a, 2017b, & 2017c), with a target of meeting 11% of heat demand by 2020 (Scottish Government, 2011). However, the chances of meeting that 11% of heat demand look far from certain.

Subsequently the Committee on Climate Change's 'Net Zero' report has recommended that the Scottish Government set a target of achieving net zero greenhouse gas emissions relative to the 1990 baseline by 2045. It also recommends that this transition "*must be fair and must be perceived to be fair*" and finds that the costs of the transition can be met at an annual resource cost (for the UK) of up to 1-2% of GDP, the same as previously expected to be needed for an 80% reduction by 2050. However, amongst other conclusions, the CCC warn that there are still no serious plans for decarbonising heating systems, that the 2040 target for phasing out petrol and diesel cars and vans is too late and the details too vague, and that afforestation targets are not being delivered (Committee on Climate Change, 2019). These conclusions serve to highlight the need for a significant ramping up of efforts to develop and deploy alternatives to fossil fuels, and the infrastructure needed to supply and distribute them. As the report notes, this will require strong leadership, and the development and delivery of policies that are stable, long-term, and investable.

Although the Net Zero report does not address how the transition should be managed fairly and equitably across the urban-rural divide, it comes at a time when the Scottish Government's proposals for decarbonising energy and tackling fuel poverty and related societal issues risk placing disproportionate demands on communities in rural and island areas, where fuel poverty and other aspects of social deprivation tend to be highest. Therefore, if the Scottish Government sees fit to adopt the recommendations it puts forward, there is a need to ensure that the resulting policies serve to rectify, rather than further exacerbate, these inequities. However, as we discuss in this paper, the direct and in-direct benefits that could be unlocked for rural and island communities by effectively managing this transition are wide-ranging and substantial.

Renewable heat met 5.9% of demand for 2017, meaning Scotland ranks as the lowest of all EU countries for renewable heat, well below the EU average of 19.5% and even below the UK figure of 7.5% (Scottish Government 2019a), meaning the rate of increase between 2016 and 2020 will need to substantially exceed the current trend. However, the elephant in the room here is that the projections for renewable energy demand for decarbonising transport show an even greater increase will be needed (Scottish Government, 2017). Unless this changes significantly in the next few years, we can expect increasing competition for resources and support for meeting the three targets, and if the past is any indicator of the future it'll be heat that will lose out (Baker, 2019; Baker, 2017).

This Common Weal policy paper was commissioned by Calor as a review of the evidence relating to a number of key questions and issues raised by the Scottish Government's policies and proposals for decarbonising heating and addressing fuel poverty in off-gas areas, with a particular focus on rural and island areas.

This paper addresses three key questions:

- What specific problems do the current and proposed regulatory regimes pose for these householders, what evidence is there for an energy inequity gap between these householders and others, and what effects will current proposals have on them in the future?
- What is the potential for different forms of off-gas heating to meet the needs of these householders, whilst also meeting policy objectives for decarbonising Scotland's energy supplies? The technologies to be reviewed will be electric heating, bioLPG, hydrogen, solar thermal, biomass and biofuels, heat pumps, heat recovery and storage technologies, and combined heat

and power (CHP). district heating systems (DHS).

- What are the current and likely future barriers and opportunities as regards the existing and proposed development of energy infrastructure for enabling alternative heating supplies in rural off-gas grid areas?

The evidence gathered for this report comes from a systematic literature review supported by interviews and email communications with experts and stakeholders. We are very grateful to all those who took the time to support this research.

1.1 Research and Policy Context

At the time of writing a number of policies and programmes are under development by the Scottish Government which will set the stage for how well, or otherwise, it will address the problems facing off-gas, rural and fuel poor households over the next decade. These are as follows:

- The Fuel Poverty (Target, Definition and Strategy) (Scotland) Bill is at Stage 3 (Scottish Government, 2019b).

- The Climate Change (Emissions Reduction Targets) (Scotland) Bill completed Stage 1 in early April 2019 (Scottish Government, 2019c).

- The suite of legislation covered by the Energy Efficient Scotland (EES) programme is subject to a new round of consultation. EES will include a Heat Networks Bill, as well as secondary legislation covering the Local Heat and Energy Efficiency Strategies (LHEES), the setting of minimum energy efficiency targets for owner-occupied and privately-rented properties, and the assessment of the energy performance of non-domestic buildings (Scottish Government, 2019d).

- The third report on the policies and proposals under the Climate Change Plan has been published, covering 2018-2032 (Scottish Government, 2019e).

- The Scottish Government has published the results of a series of consultations on the design and delivery of the Energy Efficient Scotland programme (previously known as Scotland’s Energy Efficiency Programme) which include a substantial focus on the use of Energy Performance Certificates to drive mandatory energy performance improvements (Scottish Government, 2019f).

- The revised guidance for the Energy Efficiency Standard for Social Housing (EESSH2) has been published, covering targets and proposals for beyond 2020 (Scottish Government, 2019g).

- The Scottish Government has also issued a specific call for evidence on providing low carbon heat to off-gas buildings, which is intended to support the development of a Bioenergy Action Plan and Local Energy Systems Policy Statement (Scottish Government, 2019h).

- At Westminster, the Chancellor of the Exchequer’s 2019 Spring Statement included a commitment to ban new build homes from connecting to the gas grid by 2025 (Harrabin, 2019). At the time of writing we are unclear as to whether this will be implemented through the Building Regulations or through planning policy however, as both of these are devolved powers the Scottish Government would need to legislate separately on such a ban.

- Finally, we note that all of these proposals will be impacted by the recent recommendations made by the Committee on Climate Change, which the Scottish Government has accepted, and which will inevitably require more detailed and ambitious planning, and the upgrading and bringing forward of targets (Committee on Climate Change, 2019). We also note that the UK Government is intending to adopt the Future Homes Standard under Part L of the Building Regulations. This will set out the requirements for new homes built in England from 2025, and is likely to ban new gas grid connections to these homes (and not, as has been reported in the press, the sale of gas boilers and central heating systems) (Rund Partnership, 2019).

This review is focused specifically on reviewing evidence for informing the latter call however, naturally, the scope of this overlaps with all the above, and wider, legislation. Both Common Weal and the Energy Poverty Research initiative engage extensively with the Scottish Government on these and other issues and our publications, including policy papers and consultation responses, are available from our websites.

Whilst decarbonising heat supplies to households on the gas grid has yet to be devolved, the responsibility for decarbonising heat supplies to off-gas buildings is entirely within the Scottish Government's remit. Regrettably, the Scottish Government persists in believing that energy performance certificates (EPCs) in their current form are a valid and appropriate method of assessing building energy consumption and leveraging performance improvements, and so these are currently being used and proposed as key policy drivers.

As we have previously published a number of publications covering EPCs, including a recent policy paper critiquing them and proposing an alternative approach that is entirely in line with the European Union's Energy Performance of Buildings Directive (EPBD), this paper avoids replicating that material. However, the problems caused by using EPCs are a common theme throughout (Baker & Mould, 2019; European Parliament, 2010). We also note, and support, a key conclusion of the recent review of EPCs conducted for the Scottish Government; "*The current EPC process was designed to produce an asset rating to comply with the requirements of the EPBD. What may have been sufficient as a general measure of energy performance, using a simplified energy model and an A to G banding may not be appropriate if the same system is utilised to regulate compliance with energy efficiency standards in existing buildings*" (Alembic Research et al, 2019).

Similarly, whilst much of the legislation covered here is intended to support the alleviation of fuel poverty, this report avoids replicating that material as far as possible, although some new evidence from more recent analyses is included to update this body of work. However, we would reiterate that this evidence leads us to conclude, strongly, that current policies and proposals covered by this legislation, in particular the Fuel Poverty Bill and the use of EPCs in their current form, will serve to exacerbate the impact of the urban-rural divide and further disadvantage the fuel poor and otherwise vulnerable people in rural and remote areas, who make up the vast majority of off-gas householders.

2: CHARACTERISTICS OF OFF-GAS AND RURAL HOUSEHOLDS

Around 500,000 (~21%) domestic properties in Scotland do not use mains gas as their primary source of heat (Scottish House Condition Survey, 2018a). Householders in these properties are more likely to be classified as living in fuel poverty, with 52% of those using electric heating and 40% of those using oil heating being considered fuel poor, compared to 19% of those connected to the gas grid (Citizens Advice Scotland, 2018).

In addition, approximately 17% of Scottish households are classified as being off the gas grid (as opposed to not using mains gas for primary heating) however, whilst 92% of properties in urban areas are within the coverage of the gas grid, the majority of those (64%) in rural areas lack the option to connect. Note that, for the purposes of this paper, we are using the definition reported by the Scottish House Condition Survey, which states that "*gas grid coverage is determined on the basis of the distance of the dwelling from a low/medium/intermediate pressure gas distribution pipe. Based on the usual maximum distance for standard domestic connection (63 m), dwellings are classified as being "on" or "off" the grid. This does not reflect whether the dwelling is actually connected to the grid*" (Scottish House Condition Survey, 2018a). In addition, and in light of the Committee on Climate Change's recent recommendation, we are assuming that the number of new connections allowed for existing dwellings will be minimal to nil.

Rural properties also tend to be larger and older, and are much less likely to be in multiple occupancy buildings (only 9% are in tenements or blocks of flats). Rural properties are also more likely to have technical characteristics associated with lower energy efficiency, having an average Standard Assessment Procedure (SAP) rating of 54.9, compared to 64.1 for those in urban areas. However, the rates for levels of disrepair are very similar (less than 3% difference across all categories), and the proportions of properties failing the Scottish Housing Quality Standard are only marginally higher in rural areas (46%, compared to 39%). In terms of EPC ratings, only 22% of rural properties are classified in bands B and C, compared to 46% in urban areas, and 17% are classified as in bands F and G, compared to 2% in urban areas, and a similar picture exists when properties are grouped by their Environmental Impact Rating (Scottish House Condition Survey, 2018a).

However, a mere 8% of rural households classified as being in poverty are income poor but not fuel poor, compared to 92% of those in urban areas (Scottish House Condition Survey, 2018a). This distinction is important as it relates directly to the proposals for an ‘uplift’ (or uplifts) for rural and island householders under the Scottish Government’s Fuel Poverty (Target, Definition and Strategy) (Scotland) Bill (Scottish Parliament, 2019; Scottish Parliament, 2019; Stewart, 2019). At the time of writing the Bill is about to enter Stage 3, and the Scottish Government’s full proposals and any likely amendments to the Bill remain unclear. Common Weal and the Energy Poverty Research initiative share the concern that the needs of rural and island householders have been inadequately accounted for in previous Scottish Government energy efficiency and fuel poverty policies, and in the process of the Bill so far.

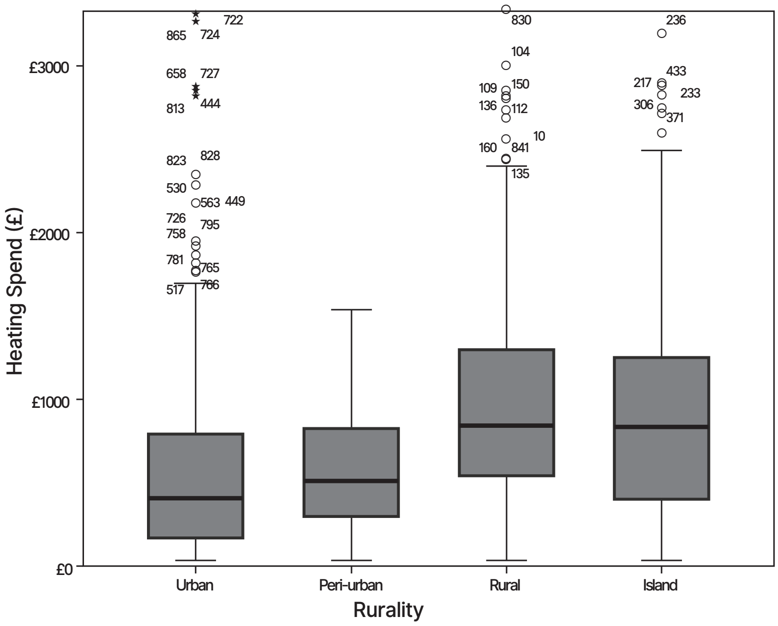
A related problem here is how these categorisations are used in practice, and their impact on the abilities of frontline organisations and support staff to improve the lives of the householders they serve. As soon as we attempt to characterise individuals, we force a simplification of reality that is defined by the complexities of individuals. Though we talk about group characteristics in this paper, it is important to keep in mind the inherent variability of households between each other and over time. Categorisation enables us to identify and describe group characteristics that may influence fuel use and the approaches adopted by fuel poverty mitigation programmes, but such high-level thinking should not be allowed to constrain the support available to any household, where evidence from individual assessments (e.g. by surveyors or support workers) points to more effective means of meeting their needs.

In urban areas we are more likely to have high numbers of homes that are similar, if not identical in terms of their energy performance and heating provisions. In contrast rural areas are much more variable in this respect. While urban homes may have one form of heating, often a gas boiler system, older rural homes are more likely to have multiple heating options. For example, rural homes with LPG heating may also have open fires, which makes measuring energy use in rural homes challenging. The direction of future travel here is uncertain and is likely to depend on the effectiveness of the Building Standards and related legislation to drive the installation of heating systems and energy efficiency measures that cost-effectively meet the needs of householders. If these are not delivered, for example by under-specifying minimum system sizes, we would expect to see greater adoption and diversification of secondary heating systems in rural areas due to the greater range of possible technological solutions available, for example wood burners, which may be banned in urban areas. Whereas in urban areas, and particularly in tenements and flats, we would expect the narrower scope of options to drive an increase primarily in electric heaters (of one form or other).

2.1 Fuel expenditure amongst rural and island households

We have previously investigated differences between rural and urban low income spend patterns by normalising as many variables as possible through project design, and in doing so uncovered significantly different average spending on fuel between urban households and those in rural and island areas. This research has shown that, when all possible variables are equal, rural and island householders spend more on fuel than their urban equivalents. Furthermore, rural and island households not only spend *significantly more* on energy for heating, but the *distributions* of expenditure across the urban-rural divide are different too. This is important due to the frequency and potentially misleading use of median averages in reporting, which obfuscates the evidence that fuel expenditure amongst rural households is highly skewed towards lower expenditures (Figures 1 and 2).

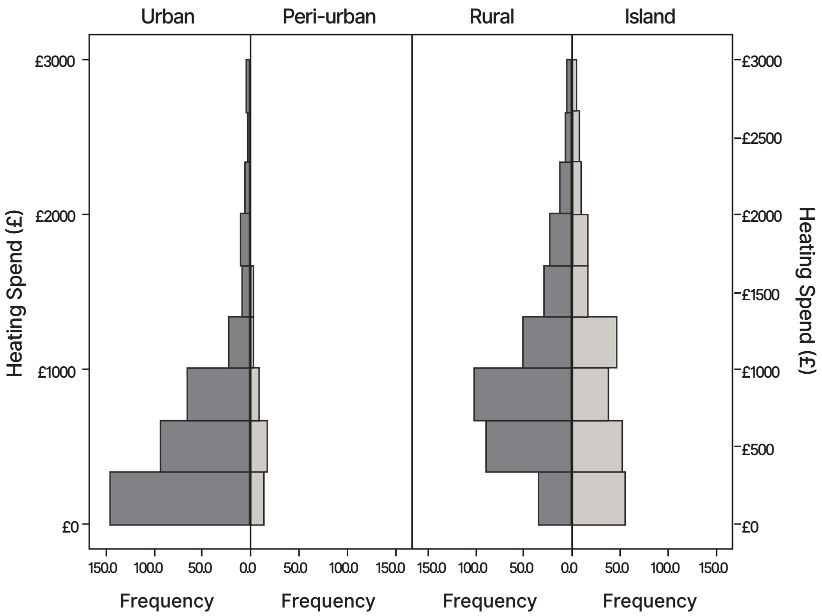
Figure 1. Distributions of Scottish household expenditure on heating by rurality



Source: Proiseact Spéird, 2016 – Data on heating energy expenditure for 1,015 households across Aberdeenshire, Argyll and Bute, Lochaber, the Orkney Isles, Renfrewshire and Skye.

Note: Skye is classified as rural, due to the biomass fuel used for heating arriving via the road bridge.

Figure 2. Distributions of Scottish household expenditure on heating by rurality



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Note: Skye is classified as rural, due to the biomass fuel used for heating arriving via the road bridge.

Since the datasets for these analyses contain real (as opposed to modelled) data they allowed robust comparisons to be made between similarly built homes and fuel types, meaning we can discount the typical assumptions that rural homes spend more on fuel because they are more likely to be larger, detached or semi-detached homes with expensive heating options. Our evidence suggests that rural low-income households actually heat their homes more than their urban equivalents, that there appears to be other behavioural differences between low income urban and rural households. These behavioural differences are not accounted for in any current modelling of domestic energy use (Atterson et al., 2018; Baker et al., 2016; Mould et al., 2014; Mould & Baker, 2017a).

2.2 Fuel poverty and the urban-rural divide

The direct measurement of fuel poverty is expensive and therefore, as is common practice, samples are taken to represent communities and proxies are also used in policy design (Morrison & Shortt, 2008). Our previous research to compare levels of fuel poverty with those indicated by the commonly used proxy of the Income domain of the Scottish Indices of Multiple Deprivation (SIMD) shows that they have a poorer correlation with each other than is suggested by official statistics (Mould et al., 2014; Mould & Baker, 2017a; Mould & Baker, 2017b; Scottish Government, 2019i; Scottish House Condition Survey, 2018b). This evidence has been accepted by stakeholders including the Scottish Government's Fuel Poverty Strategic Working Group, and is included in the academic panel review of the fuel poverty definition (Bramley et al., 2017; Scottish Government, 2016a). The latter report also stresses the need to make more and better use of real (as opposed to modelled) data to improve the targeting and delivery of measures for alleviating fuel poverty, a recommendation so far rejected by the Scottish Government.

The SIMD income domain and the overall SIMD score are two factors which have been used for apportioning higher funding rates, for example under the Energy Efficient Scotland programme, the Local Heat and Energy Efficiency Strategies, and the UK's Energy Company Obligation (Ofgem, 2019; Scottish Government, 2019d). Both Ofgem and the Scottish Government have recognised this issue and introduced specific funding streams within these programmes targeted at rural areas or a rural uplift factor which increases the amount rural households can access.

The passing of the Scottish Government's Fuel Poverty (Target, Definition and Strategy) (Scotland) Bill, which is currently awaiting the start of Stage 3, will almost certainly lead to the adoption of the Minimum Income Standard to determine the minimum income level. The proposals also state the intention that regulations must identify "remote rural areas", "remote small towns", and "island areas", although these are not a direct match with the current urban rural classification system, which does not include any classification(s) for island areas (Scottish Government, 2018a). An Island Communities Impact Assessment (ICIA) has been conducted for the Bill however, it derogates any substantial or meaningful assessment to a forthcoming ICIA on the Fuel Poverty Strategy (Scottish Government, 2019k). In addition, the proposals state that the regulations should specify an official (as yet undetermined) who will determine the uplift(s) to be applied to these areas, and there will also be an uplift for those with additional extra costs, such as people receiving benefits for care need or disability. The latter is one result of a series of amendments put forward by Jackie Baillie MSP with support from Energy Action Scotland, and backed by a number of organisations including Common Weal and the Energy Poverty Research initiative (Davis et al., 2018; EAS, 2019; Scottish Government, 2019b).

Whilst any adjustment that reflects the evidence on the significant differences between fuel poverty in rural and island areas and urban areas should be welcomed, limiting such adjustments to remote islands is a policy mis-step. A key point raised by Orkney Islands Council as part of this research is that the islands have plentiful supplies of renewable energy, including substantial but barely exploited tidal energy resources, yet lack the grid capacity to connect these and export excess generation to the mainland. This means, unusually, that technical fixes and electric heating systems could have a significant role to play in tackling fuel poverty in such remote areas if local grids (including energy storage technologies) were to be established, and management of these devolved to the local level. Under this scenario households could be fitted with electric heating systems supplied by locally-generated, low cost, renewable electricity. Furthermore, such a scenario would also serve to mitigate a key threat posed by upgrading connections to the islands, whereby social inequality would be exacerbated if richer residents capitalise on the additional capacity to export electricity by installing privately-owned wind turbines on their land and so compete for sales with public and community-owned generators (Fraser, 2019). For this reason, it would seem sensible to allow local authorities to implement moratoria on new private generators in grid-constrained areas being allowed to export excess electricity beyond the local grid, with prices for exporting to local grids (if such additional capacity is needed) set locally. Note that at the time of writing Ofgem is “minded to approve” a 600MW link to the Orkney and Shetland Islands, and a 450MW link to the Western Isles (Scottish Government, 2019m).

Finally, a simple measure that would reduce the energy costs of householders in remote areas, and so tackle fuel poverty in areas where levels are highest, would simply be to remove all regulatory levies from these households (who can be identified by the distribution network operators by their meter point data). Ofgem’s analysis of electricity bills in August 2018 showed that these costs comprised 17.45% of final bills (Ofgem, 2018) and, for the comparatively few customers involved, elimination of these levies would make a significant difference, but at a relatively low socialised cost (Wright, 2019).

2.2.1 Questioning the validity of proxy metrics for tackling fuel poverty

In questioning the validity of the existing proxy metrics used to target funding towards fuel poor households we tested alternative metrics for a correlation to fuel poverty. Using data from the Scottish House Condition Survey (SHCS) we tested the percentage of households with loft insulation and central heating against the percent in fuel poverty. There is very little variation with the proportion of households having central heating between local authorities, with the exception of the island authorities. Even the three island authorities (Orkney, Shetland and Na h-Eilean Siar) report their proportion of households with central heating to be 87, 82 and 91% respectively, and the prevalence of loft insulation as reported in the SHCS did not correlate closely with the prevalence of fuel poverty within local authority areas (Figure 3).

Figure 3. Fuel Poverty and Loft Insulation SIMD domain

The SIMDs combine seven different domains (aspects) of deprivation: income; employment; health; education, skills and training; geographic access to services; crime; and housing. Taking the reported number of datazones in the bottom quintile we calculated what percent of the total datazones this represented for each local authority and compared these figures for the SIMD domains with the proportions of fuel poverty in rural and island local authority areas (Scottish Government, 2016b). Figures 4 to 10 show the results of these simple analyses.

Income and the closely related domain of employment show similar distribution patterns, but neither correlates well with the fuel poverty metric (Figures 4 and 5). Similarly, plotting the housing, education, crime and health domains did not show a good correlation with the fuel poverty metric (Figures 6, 7, 8 and 9).

Figure 4. Fuel Poverty and Income Domain (% datazones in lowest quintile)

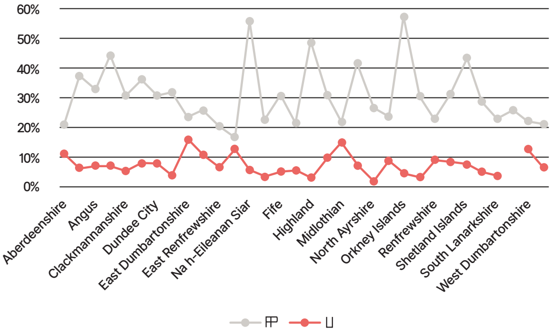


Figure 5. Fuel Poverty and Employment Domain (% datazones in lowest quintile)

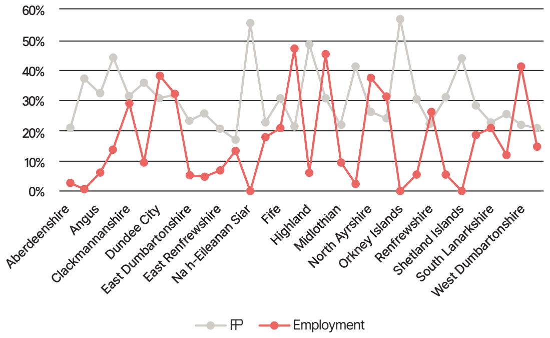


Figure 6. Fuel Poverty and Housing Domain (% datazone in lowest quintile)

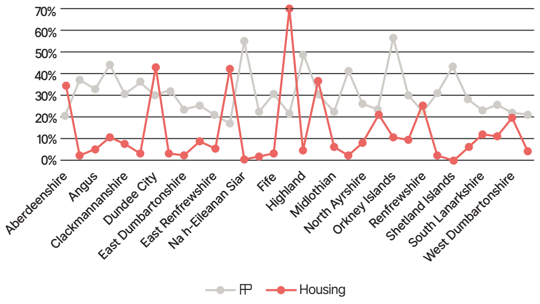


Figure 7. Fuel Poverty and Education Domain (% datazones in lowest quintile)

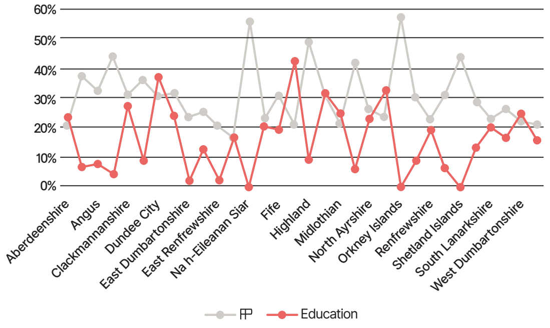


Figure 8. Fuel Poverty and Crime Domain (% datazones in lowest quintile)

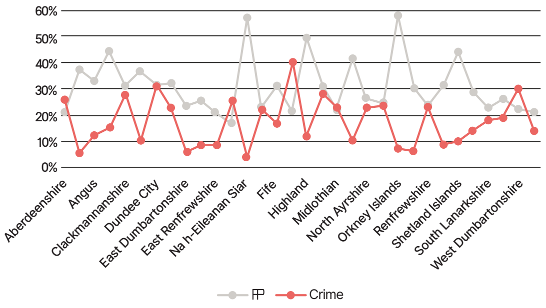


Figure 9. Fuel Poverty and Health Domain (% datazones in lowest quintile)

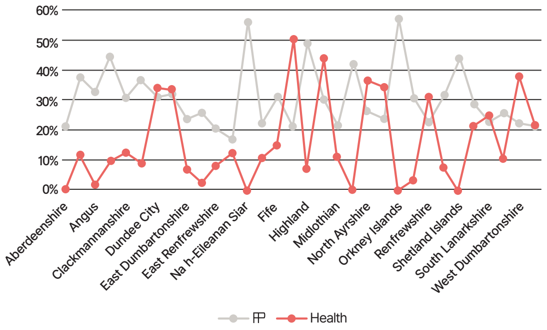
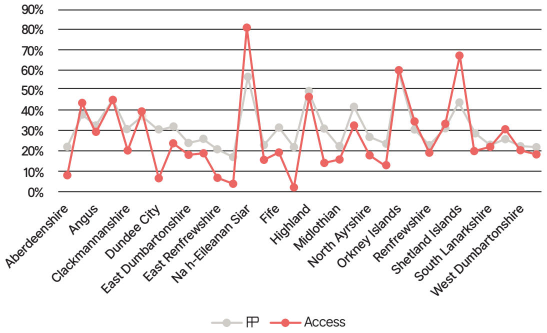


Figure 10. Fuel poverty and Access Domain (% datazones in lowest quintile)



This left us with the Access domain. This domain is a measure of how accessible dwellings within the datazones are to public transport and amenities; effectively this is a measure of rurality. Considering the correlation shown in Figure 10 it is evident that it is this metric which most closely matches the fuel poverty metric in the proportion of datazones in the lowest quintile. Testing each of the factors for their correlation to the fuel poverty metric and ranking them from most closely correlated to least we find the results shown in Table 1.

This correlation should come as no surprise given the evidence on the linkages between the recognised condition of fuel poverty and the neglected condition of transport poverty, which are themselves both aspects of vulnerability (Berry et al., 2016; Mattioli et al., 2016; Mattioli, 2015; Sovacool et al., 2012). Furthermore, transport / access poverty itself serves to exacerbate the democratic deficit in Scotland, where on average one 'local' representative serves 4,270 people, compared to 2,860 in England, 400 in Germany, and 200 in Austria, with householders in rural and remote areas often having to travel many hours to access political representation and centralised public services face-to-face. This is a core issue Common Weal is addressing as part of our wider campaigning activities (Bell, 2018; Kinghorn-Gray, 2018; Ryan, 2018).

Of course, fuel poverty, transport/access poverty, and the democratic deficit are themselves all aspects of the wider condition of vulnerability, yet the need to develop a Scottish definition of vulnerability was another recommendation made in the academic panel review of the fuel poverty definition that has so far been rejected by the Scottish Government (Bramley et al., 2017).

Finally, Table 1 shows the correlation factors between the fuel poverty metric and the SIMD domains, plus the SHCS metrics for loft insulation and central heating, and shows that the income domain of SIMD is one of the least reliable proxies for fuel poverty, whilst the access domain has the closest correlation. After access, central heating is the most reliable but this is a weak correlation and would require further investigation to ascertain the degree (or not) of causality, even though non-specialists might infer this, whilst loft insulation and housing barely correlate at all despite being technical metrics. It also illustrates that, by using either the income domain score or the overall SIMD score as proxies for fuel poverty we have at best a less than 50/50 chance of finding a fuel poor household. Even with the best intentions embedded in a policy we are in reality leaving the possibilities of a positive outcome to a poor chance, if not actually disadvantaging the disadvantaged further by focusing funds into homes which are not most in need.

Table 1. Correlations of SIMD domains and SHCS loft insulation metric with the fuel poverty metric ranking, for datazones in the lowest quintile

Metric	Correlation factor
Access Domain (SIMD)	0.88446
Central Heating (SHCS)	0.63391
Education Domain (SIMD)	0.54722
Crime Domain (SIMD)	0.52203
Health Domain (SIMD)	0.42605
Employment Domain (SIMD)	0.40862
Income Domain (SIMD)	0.40456
Loft Insulation (SHCS)	0.37759
Housing Domain (SIMD)	0.36621
Overall SIMD score	0.094196

Note: Domains are % of datazones in the lowest quintile, 2016. Correlation of metrics is with the currently reported fuel poverty metric, 2015-17.

For further illustrations of the regional distributions of these statistics see the figures in the Appendix.

2.3 Impacts of current policy proposals on rural and off-gas households

At the time of writing the Scottish Parliament is in the process of passing the Fuel Poverty (Target, Definition and Strategy) (Scotland) Bill (Scottish Government, 2019b). The Bill has three key components:

— It sets targets to achieve a reduction of Fuel Poverty to 5% by 2040;

— It revises the Scottish definition of fuel poverty;

— And it sets obligations on regular reports on the levels of fuel poverty.

The Bill was both lauded as ambitious and condemned for its lack of ambition and inherent scrutiny of progress. In particular, we have previously raised a number of concerns as regards the impacts of the Bill on rural, remote and off-gas households which, in our view, will serve to further disadvantage these householders and exacerbate the inequalities between fuel poor householders across the urban-rural divide. These are:

- The continued reliance on a GB oil price underpinning the fuel poverty model, rather than a Scottish, or even a rural / island price for oil;
- The lack of an adjustment to the income metric to reflect the true extent and nature of fuel poverty in rural and island areas
- The intention to use Energy Performance Certificates (EPCs) to mandate householders to make energy efficiency upgrades to their homes (Baker et al., 2016, 2018 & 2018; Baker & Mould, 2018; Mould et al., 2014).

Our concerns over the impact of using EPCs as a driver for policy, and particularly when applied to off-gas and rural/remote households, have been echoed by stakeholders including Calor, the Scottish Federation of Housing Associations (SFHA), Hebridean Housing Partnership, and Orkney Islands Council, as part of the research conducted for this report, and previously by other stakeholders and experts in our open letter to the Scottish Government (Baker et al., 2018). In response to these long-standing and growing concerns over the validity and use of EPCs, Common Weal has previously published a full critique and our proposals for an alternative EPC which would better meet the needs of both households and the European Union’s requirements under the Energy Performance of Buildings Directive (Baker & Mould, 2018). Whilst we naturally support the technical recommendations made in the recent review of EPCs (Alembic Research et al., 2019), and accept that modelling will always be required as part of the consent process for new build, the costs and benefits of investing in incremental improvements in modelling need to be set against those of making more and better use of real data, as recommended by the academic panel’s review of the Scottish definition of fuel poverty (Bramley et al., 2017).

Also, of serious concern are the costs of the proposals for social landlords under the Scottish Government’s Energy Efficiency Standard for Social Housing post-2020 (EESSH2), which was raised by the Scottish Federation of Housing Associations as part of their evidence for this report. Whilst the modelled costs per dwelling of meeting EESH2 range between £4,800 and £6,900, the total modelled costs to local authorities range from £1.5 to £1.7 billion, the total modelled costs to registered social landlords (RSLs) range from £1.9 to £2 billion, and the average savings to householders will amount to a mere £160 per year (Scottish Government, 2018b). Other problems raised by the SFHA were how to explain to tenants that not all properties will be upgraded to meet the standard, and RSLs lacking access to energy efficiency funding (SFHA, 2019). Finally, whilst the main model adopted for these calculations accounts for a wider range of measures than the National Household Model, it omits options such as connection to district heating networks, thermal storage technologies, site-specific renewables (geothermal, etc) and deep retrofits.

As regards privately-owned properties, the proposals under the new Energy Efficient Scotland programme, currently out for consultation, include a requirement for all dwellings to achieve a minimum EPC Band C rating by either 2030 or 2025 at the point of sale or rental, although the consultation notes that even under the more ambitious date there would still be a backlog of unimproved dwellings post-2040 (Scottish Government, 2019d). From attendance at the consultation event held in Stirling on May 9 2019 we are under the impression that the Scottish Government is focusing on addressing the poorer energy performance of privately-rented stock, which would indeed be impacted significantly more by this proposal, and that it may be minded to include a short (1-2 year) period whereby the improvement could be achieved post-sale or rental, with the clock not stopping should the dwelling be sold or rented again in this period. This latter proposal would enable private landlords to offload dwellings they cannot afford to upgrade (at reduced values), and has been successful as part of the Residential Energy Conservation Ordinance (RECO) legislation implemented in many states in the USA, and recommended to the Scottish Government at least as far back as 2012 (Baker et al., 2012).

There is also the question of how the performance of the building stock, particularly older and traditional buildings, will be able to physically adapt to the differing heating and cooling load patterns of electric and other alternative and supplementary heating systems (STBA, 2012). This concern is particularly strong for rural and island areas due to the higher numbers and greater diversity of such buildings in these areas.

Further concerns raised by the proposals include:

— The continued lack of support for solar thermal heating (in 2016 the combined contributions of solar thermal and heat pumps met just 11% of Scottish renewable and low carbon heat capacity) (EST, 2017);

— The affordability and emissions savings of a number of technologies for heating off-gas households (e.g. electrolytic hydrogen and air source heat pumps);

— The lack of consideration of the site-specific nature of many renewable and low carbon heating technologies (e.g. water source heat pumps);

— The lack of consideration of how the proposals may need to consider island areas differently due to the availability of (currently) unexportable excess renewable electricity;

— And the lack of consideration of the 'Danish model' of multi-technology district heating, despite substantial evidence of its potential for adoption in Scotland.

The next section of this report reviews the evidence for different technology and fuel options for reducing emissions and tackling fuel poverty amongst off-gas households.

3: TECHNOLOGY AND FUEL OPTIONS FOR HEATING OFF-GAS HOUSEHOLDS

This section reviews the evidence for the strengths, weaknesses, opportunities and threats of a range of key technology options for providing renewable and low carbon heat to off-gas households in Scotland, as well as their costs and potential contributions to tackling climate change and fuel poverty.

The figures provided here have been drawn from both a systematic literature review and information reported by those consulted as part of this work. We have aggregated these as far as possible within the limits of what is reasonably comparable (e.g. in terms of the measures reported, time of publication, etc) and noted any caveats which should be borne in mind when interpreting the figures, especially where comparing figures from different tables. Putting precise, comparable, figures on costs is invariably fraught with uncertainties, however, in most cases we did find a good degree of consistency amongst the sources, the main exception being for hydrogen.

The opening section summarises the costs and savings from common heating types. This is followed by sections covering specific technologies, fuels, and combinations of these. The selection of technologies is limited to those that can provide heat (or heating fuels) directly, so renewable electricity technologies such as solar photovoltaics and wind turbines are excluded beyond noting their ability to provide zero carbon electricity for other technologies. Although it was our original intention to disaggregate these to the level of individual technologies there emerged some natural groupings around some issues, such as site-specificity and optimal technology mixes, that form a narrative to the findings, and we hope this is better reflected in this more aggregated structure.

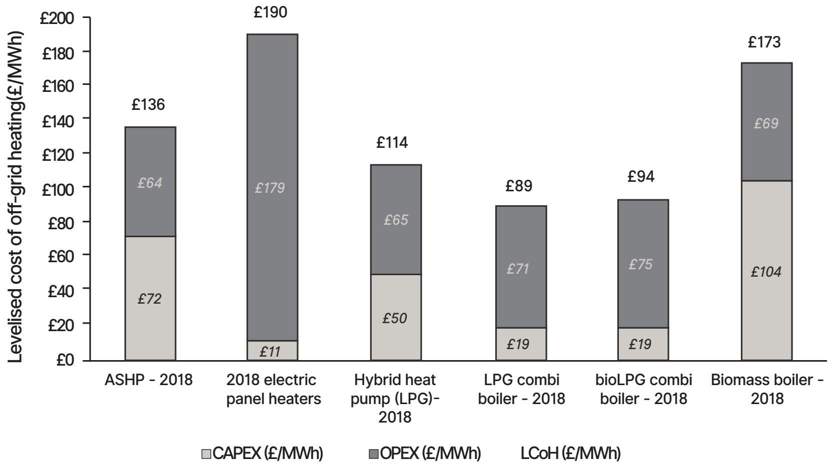
3.1 Costs and savings from common heating types

Figures for the average costs of individual domestic heating systems are presented in Table 2. These were aggregated from a range of reliable sources and found to be largely consistent for 'average' systems (2-3 bed house, typical build type, typical occupancy, etc) over the period covered, and are generally consistent with the figures reported in the sections that follow. However, the characteristics of many off-gas and rural properties and households frequently vary far from such average archetypes (see

Sections 2 to 2.2), generally meaning that we would expect costs for these to be at the upper ends of the ranges. For further comparison, Figure 11 in Section 3.5.4 gives the levellised costs for installing and running a range of renewable and low carbon heating systems in a typical off-gas rural property. This was included in the evidence provided by Calor to inform this paper.

Table 3 reproduces the costs most recently reported by the UK and Scottish Government for four renewable and low carbon heating technologies, with the caveats that these are averages, self-reported, and limited to installations funded through the Renewable Heat Incentive (RHI). With the exception of solar thermal, this evidence indicates that the 'real' costs of these systems are higher than have previously been assumed. The likely reason for this being that householders are finding the need to install higher than 'average' capacity systems to meet their space heating needs. This would explain the consistency for solar thermal as the primary use of this technology is often for heating water, which can then be stored until needed in a conventional cylinder.

Figure 11. Levellised costs of options for decarbonising a typical rural off-gas grid house



Source: Ecuity Consulting, 2019.

Note: Calculations are for a typical rural, off-gas house using 14,080kwh/year of heat.

Table 2. Energy costs for central heating, 2015-2019

Energy source	Cost of heat (p/kWhth)	Average Cost of a system install
Electric (storage heaters)	16.0	£1,000-£2,500
Pellets	7.1	£9,000-£15,000
LPG	6.4	£3,000-£5,000
Gas Oil	5.6	£4,000-£6,000
ASHP	5.5	£6,000-£8,000 (£10,000 for exhaust ASHPs)
Wood	5.3	No comparable figure
Kerosene	4.6	No comparable figure
Gas	4.5	£2,000-£3,000
GSHP	4.4	£11,000-£15,000
Solar thermal (to meet ~1/3 demand)	No comparable figure	£3,000-£5,000

Sources: CAT, 2019; EST, 2018; EST, n.d.; Ingrams, n.d.; Mould, 2019; Ovo Energy, 2015.

Notes: Figures are for the UK, March 2015. Figures account for average boiler / system efficiencies.

Table 3. Average self-reported costs of domestic RHI installations (Apr/14 – Dec/17)

	Capacity	Median cost	Median cost per kW
Air Source Heat Pump	8 kW	£7,500	£970
	12-13 kW	£10,850	£865
	16 kW	£12,430	£780
Ground Source Heat Pump	8 kW	£14,860	£1,860
	12-13 kW	£18,330	£1,475
	16 kW	£24,060	£1,500
Biomass Boilers	10-20 kW	£9,713	£694
	20-30 kW	£14,121	£583
	30-45 kW	£19,759	£534
Solar Thermal	3-5 kW	£4,983	£1,277

Sources: BEIS, 2018; Scottish Government, 2019h.

The following sections review recent evidence on these and other technology and fuel options, beginning with electric heating as the 'business as usual' technology and then presenting the other options in alphabetical order.

3.2 Electric heating

Strengths

- Default option for off-gas households
- Low install costs
- Familiar to householders
- Infrared systems can provide high levels of thermal comfort and indoor air quality

Weaknesses

- Emissions savings ultimately limited by the grid electricity mix (except where met by other local renewable systems).
- Storage heater controls are not operated by residents to maximise the efficiency and effectiveness of the systems.
- Electricity costs for storage heaters are so high that they would not normally be considered for a property using ~20 MWh per year (e.g. an old 4 bed detached house).
- New heating technologies (e.g. IR panels) not being developed for maximising gains from off peak supplies (Ofgem counts Economy 10 as a 'non-standard' tariff).

Opportunities

- Familiar to installers and energy advice services
- Potential for some uptake of infrared systems, but limited by building and occupant characteristics

Threats

- Highest energy costs of any conventional technology
- Development of policy is failing to keep pace with advances in technology

Sources: Alban, 2010; Anastaselos, 2011; Atterson et al., 2018; EST, n.d.; Frerk & MacLean, 2017; O'Donnell, 2019; Ovo Energy, 2015; Scottish Government, 2019h.

Electricity is the primary energy source for 12% of Scottish households, including the majority of off-gas households (SHCS, 2018). Traditionally electric heating systems have used storage heaters however, for larger and older properties which are disproportionately represented in rural Scotland, electricity costs are so high that they would not normally be considered as an option for heating (Frerk & MacLean, 2017). One likely consequence of this is that the numbers of households adopting panel heaters and heat pumps is increasing, and emergent technologies such as infrared heaters are now being trialled at scale, for example by Hebridean Housing Partnership (O'Donnell, 2019).

There are a number of arguments in favour of converting more off-gas households to electric heating; however, ultimately, the benefits of this approach are reliant on the resulting increase in electricity demand being met from renewable sources, and at competitive prices. This outcome is currently far from certain due to a number of threats, not least the significant rise in demand from electric vehicles as diesel engines are phased out and consumer demand grows. This threat was raised by Scottish Power Energy Networks (SPEN) (SPEN, 2019), which also commented that they do not have a clear indication of if or when the electrification of heat will happen at scale. This lack of a long-term signal to the industry poses a threat to the potential for Scotland to achieve the Committee on Climate Change's recommendation of net zero emissions by 2045 (without, of course, adjusting the figures by securing a devolved grid emissions factor) (Committee on Climate Change, 2019), and is one of several factors leading to our predictions of a 'perfect storm' facing efforts to decarbonise heat supplies in Scotland (Baker, 2017 & 2019).

The Scottish Federation of Housing Associations notes that electric heating benefits from low connection and installation costs, and particularly for off-gas and rural/remote households for which the capital costs of alternative systems are higher. This point is accepted by the Scottish Government (Scottish Government, 2019h), and was noted as a barrier to alternative heating systems by SPEN, who are arguing for policies to be based on the whole life costs of technologies and wider assessments of their benefits, e.g. strategic return on investment (SROI) figures. However, as noted by another of our consultees, the high recurrent cost of electric resistance heating creates a real problem, i.e. fuel poverty is worsened and the objectives of health and social policy move further away from being met (Olivier, 2019a).

For reasons detailed elsewhere in this document we would generally expect wider assessments of the benefits of other technology options for heating off-gas households to be more favourable than conventional electric heating. However, there are exceptions to this, particularly in the islands where local renewable costs and excess (unexportable) generation make electric heating a much more attractive option for fuel poor households. As such, there is little evidence to suggest that a policy strategy that relies heavily on the nation-wide conversion of significant numbers of off-gas households to electric heating is an optimal solution for Scotland, and strong evidence to suggest that such a strategy could pose a significant risk to meeting the Scottish climate change targets.

3.2.1 Emerging electric heating system technologies

Whilst it is relatively simple to draw conclusions on conventional electric heating systems and heat pumps there remains a paucity of evidence on more recent technologies. We have previously concluded that the development of policy is failing to keep pace with advances in high efficiency electric heating, storage and smart grids (Atterson et al., 2018). The most immediate implication of this, noted as a key barrier by Hebridean Housing Partnership, is that the SAP ratings for some systems may be artificially low, resulting in them not qualifying for funding under EESSH (etc).

For example, HHP have installed over 100 infrared heating systems in solid wall properties and, with some caveats, report high levels of householder satisfaction. Whereas conventional electric heaters use convection to circulate heat around living spaces, infrared heating systems operate as radiative panels that direct heat largely into the building fabric. Their main reported benefits are high levels of thermal comfort and indoor air quality. However, this requires occupants to adopt a heating regime whereby they continue to pump heat into their walls before and after the start and end of the heating season, which is released passively during the winter. This heating regime harks back to the way traditional stone buildings were heated and the evidence agrees with the wider arguments for the benefits of high thermal mass construction, which is needed to create the combination of sufficiently high air and radiant temperatures necessary to create an adequate feeling of thermal comfort. However, in a warming climate, this regime risks causing overheating if the building fabric reaches and exceeds its thermal capacity in the summer months. As such, the overall potential of infrared systems is likely to be limited by their building-specific benefits, as well as the willingness and capacity of occupants to change their heating habits, which also means buying more electricity when energy prices are higher. The latter barrier, and the risk of overheating, could be addressed through smart technologies, and indeed HHP are trialling in-wall sensors. However, more evidence is needed to determine how effective this approach is in real world conditions, so we are left to conclude that such newer forms of electric heating are likely to be attractive solutions for some specific building and occupant types, and so should be treated with caution as well as a degree of flexibility by policymakers (Alban, 2010; Anastaselos, 2011; O'Donnell, 2019; Olivier, 2019a).

3.3 Building-mounted solar thermal

Strengths

- Low cost of installation.
- Low cost of heat.
- Low maintenance.
- Familiar technology.
- Highly flexible – suitable for most buildings and for integration with other heating systems.

Weaknesses

- Standard-sized arrays will not meet 100% of heating demand.
- Benefits to householders in tenements and flats are diluted by the shared roof space.
- Supply of useful heat dependent on occupant lifestyles (excluding when connected to heat storage technologies).
- Existing heating settings and householder behaviours need to be altered to fully benefit from the technology.

Opportunities

- Low market penetration in Scotland.
- High potential for use as part of tackling fuel poverty.
- DIY systems are cheaper (but do not qualify for incentive schemes).

Threats

- Payback periods are dependent on incentives/subsidies.

Sources: Andreadis et al., 2013; EST, 2019; Ingrams, n.d.; Renewable Energy Hub, 2018; Scottish Government, 2012

Solar thermal heating panels, which can be mounted on and integrated with existing buildings and heating systems with minimal disruption to the building fabric, are a highly unexploited technology in Scotland. Yet despite their potential as a low cost and 100% renewable solution to providing domestic heating their contribution is negligible (being a mere 9 GWh total output for 2010) (Scottish Government, 2012). Further figures for installations in Scotland are included in Table 4; however, the annual contribution is so small as to be frequently obfuscated in official statistics.

Table 4. Solar units installed in Scotland by different sources: Ofgem, Element Energy Ltd., and Scottish Government

Source	PV		Solar thermal	
	Ofgem	Element Energy Ltd.	Scottish Gov.	Element Energy Ltd.
Number of units/ stations installed	112[a]	95	n/a	10,700–11,100
Installed capacity (kWp)	382[b]	414	9370	22,400–23,400
Energy output (MWh/yr)	n/a	352	6666	14,400 – 15,000
Date	31-03-2010	08-2008	31-03-2009	07-2008

Source: Andreadis et al., 2013.

Table 5 gives shows the annual fuel cost and CO2 savings for solar water heating compared to other forms of heating. However, the precise savings offered by solar thermal systems are dependent on a large range of factors, these include:

- Initial system cost (depending on size, quality of parts and installation);
- The energy source being replaced (coal, gas, electricity, LPG, oil, etc.);
- The property's suitability for solar panels and the total output of the system (usually between 1000-2500kWh in the UK);
- The property's energy efficiency;
- Availability of and eligibility for incentive schemes e.g. the Renewable Heat Incentive (RHI)
- Household geographical location and solar resource;
- The cost of the fuel used for any supplementary water heating system, e.g. a gas boiler.
- And household lifestyles and energy needs.

(Source: Renewable Energy Hub, 2018).

Table 5. Annual fuel cost and CO2 savings for solar water heating compared to other forms of heating, by fuel type, 2018-2019

Existing system	Annual fuel bill savings (£/year)	Annual carbon dioxide savings (kgCO2/year)
Gas	£50-£60	270 kg
Oil	£55-£75	350 kg
Coal	£55-£65	540 kg
Electricity	£80-£95	390 kg
LPG	£95-£100	310 kg

Sources: EST, 2019; Renewable Energy Hub, 2018.

Notes: Figures for 2018-19. Figures account for full install costs. Figures exclude savings from incentive schemes.

Fitting solar thermal panels costs between £3,000-£6,000 per household, for a saving of between £50-£100 per year on average energy costs, and excluding savings from incentives. The upper end of that cost range also includes necessary upgrades, such as new hot water tanks, which are frequently excluded from costings for more expensive technologies. The payback period for an average household installation being 10-15 years if the Renewable Heat Incentive is applied, and whilst DIY systems do not qualify for the RHI this can be offset by their lower installation costs. And whilst a solar thermal system will typically meet only 40%-60% of household demand, additional heat storage systems can be installed to maximise their contribution at times when demand is high but output is low (Andreadis et al., 2013; EST, 2019; Ingrams, n.d.; Renewable Energy Hub, 2018).

Finally, it is important to note the success of domestic heat batteries as an enabling technology for solar thermal, as pioneered in Scotland by Sunamp. These have comparable costs to hot water tanks and lower total costs of ownership, lower costs of energy storage and lower lifecycle impacts (compared to electrical batteries). As of July 2018, Sunamp had installed 766 heat battery products in over 625 homes, achieving a target of saving these households 20% on space and/or water heating. The technology is also suitable for other heat storage applications, including as part of district heating networks (Bissell, 2018).

Unlike the findings for many of the other technologies covered in this report that are couched, to a greater or lesser extent, in a number of caveats, the conclusions on solar thermal heating systems are simple. Whilst the technology is not a silver bullet for meeting all heating demand for every type of home, its costs and savings, and potential for tackling fuel poverty, mean solar thermal should be seen as a key, essential option for decarbonising domestic heating, and one which the Scottish Government has so far insufficiently supported.

However, as the next section discusses, if the Scottish Government's support for building-mounted solar thermal has been poor, its support for its big brother, large scale arrays, has been non-existent.

3.4 District heating - large scale solar thermal, biomass district heating with inter-seasonal heat storage

Strengths

- Very low cost of heat - around 30 to 50 €/Mwh.
- High emissions savings.
- Solar thermal has the potential to meet >50% of energy supplies to district heating systems.
- Inter-seasonal heat storage technologies are simple, reliable, low-cost, and add significantly to overall system efficiencies.

Weaknesses

- Cost and emissions savings dependent on overall district heating system efficiency,
- integration of thermal storage, and emissions costs of biomass
- Availability and cost of land for solar arrays

Opportunities

- Significant successes seen in Denmark, Austria, etc, provide a model that could be directly adopted in Scotland.
- Development of fuel supply chains offers significant direct and co-benefits to local communities.

Threats

- To date, no such systems exist in Scotland.
- Lack of visibility and knowledge amongst decision-makers in Scotland
- Lack of strategic planning for DHS by the Scottish Government

Sources: Baker & Mould, 2019; Danish Energy Agency, n.d.; Donnellan et al., 2018; EST, 2017; Ofgem, 2015; Olivier, 2019b; Ramboll, 2015; Solar District Heating, 2018; Wien Energie, 2019.

Whilst many of the technologies covered in this report can be used to supply district heating systems (e.g. energy from waste, heat pumps, etc) we wish to draw specific attention to the ‘Danish model’ of district heating that combines multiple technologies to deliver significant cost, emissions and efficiency savings, whilst offering a wide range of co-benefits to local communities. The three cornerstone technologies employed are large scale solar thermal, biomass, and inter-seasonal heat storage. The biomass component of the supply can cover a range of fuel stocks, including sustainable wood fuel supplies and energy biogas from waste, or can be replaced with heat recovery from large sources of waste or pumped from renewable heat supplies. However, the approach requires all of these technologies to be truly effective, and the greatest benefits are unlocked by projects that utilise and develop local fuel supply chains.

Costs for connection to systems based on this model are also low and, counter-intuitively, are not significantly higher in rural areas, even before accounting for co-direct benefits. Connection costs for the approach deployed in Vienna, Austria are as low as £5,000 per household for normal density urban housing (Pöyry, Faber Maunsell & AECOM, 2009), rising only to £7,000 per household for very low-density suburban to semi-rural housing around Copenhagen, Denmark (Olivier, 2019b). In comparison, costs of connection to more conventional district heating in urban Sheffield have amounted to £6,100 - £7,200 per household (Pöyry, Faber Maunsell & AECOM, 2009).

The Scottish Government has set itself the target of delivering 1.5TWh of heat demand from district or ‘communal’ heating (Scottish Government, 2016b), yet differences in how data has been gathered and statistics are reported (e.g. by household connections, specific fuel types, etc) and incomplete data mean that in practice it is currently difficult to accurately gauge progress against this target (EST, 2017; Ofgem, 2015). A cynic would suggest one reason for this is that policymakers are concerned that the national picture is not an optimistic one. It’s far easier for them to point to specific examples of operational systems in places such as Lerwick (Shetland) (Siemens, 2011), Aberdeen (Aberdeen City Council, 2017), Calside (Renfrewshire) (CarbonPlan, 2018), Edinburgh (City of Edinburgh Council, 2015), and Glasgow, where the public profile of DHS was raised by its incorporation in the design of the athletes’ village for the 2014 Commonwealth Games (Euroheat & Power, 2016); and essentially leave it to industry and local authorities to come up with new projects and compete for funding. All of this serves to obfuscate the detail of what is, and isn’t, actually happening.

As such, the consideration of technology choices and fuel supplies remains largely absent from Scottish Government thinking on developing district heating, and the use of large scale solar thermal is currently completely absent, e.g. a recent report commissioned by ClimateXChange Scotland makes no mention of solar thermal or this model, and includes very little on technology choices in general (the word ‘solar’ appears once, in relation to Germany’s grid electricity mix) (Donnellan et al., 2018).

This multi-technology approach has been successfully implemented by a growing number and size of district heating networks across Europe. Denmark leads the world, and hosts nine of the largest solar thermal plants in Europe, including Dronninglund (26MW_{th}) (PlanEnergi and Niras, 2015), Marstal on the island of Aeroe (23MW_{th}) (GSTE, 2014), and 13MW_{th} installations at Grasten and Braedstrup. Dronninglund and Marstal use gravel-lined pits to provide inter-seasonal thermal storage, whilst Braestrup uses boreholes (Stadler, 2014). Significant investments in district heating using this same model have also been made by Norway and Austria is now making significant investments in solar thermal (Baker et al., 2019a; IET, 2012; Mauther et al., 2014; Wien Energie, 2019). In 2011 the estimated capacity was a mere 13MWh however, in 2012 the development of a large installation to supply the Lillestrøm district heating system added 4GWh to capacity.

Of particular note is that generation costs for this multi-technology approach are highly competitive, currently around 30 to 50 €/MWh (Solar District Heating, 2018). This makes the approach highly attractive both for investors and as an option for tackling fuel poverty yet, to date, the approach has yet to be implemented in Scotland. However, as part of the research for this report we became aware of a project being developed by AES Solar which would be the first of its kind in Scotland.

This is covered in full in our policy paper on developing successful district heating in Scotland (Baker & Mould, 2019).

3.5 Energy from Waste, BioLPG, Biopropane, Biogas, Anaerobic Digestion, and Thermal Hydrolysis

Strengths

- Low cost of fuel and installation – fuel costs comparable with LPG via gasification.
- High emissions savings - biopropane offers a ~90% reduction in emissions compared to LPG via gasification.
- BioLPG can be used as a direct replacement fuel for LPG boilers, without the need for replacing boilers, piping, radiators or storage tanks, and such systems are compatible with solar thermal systems.
- Bio LPG can be used as a fuel for LPG hybrid heat pumps.
- Flexibility of fuel stocks for production means these are plentiful and can be adapted to local availability.
- Attractive returns on investment.
- Generally compatible with existing technologies and infrastructure (boilers, central heating systems, etc).
- Fermentation skills base in Scotland is good.

Weaknesses

- Some systems (e.g. large anaerobic digestion plants) have high up-front costs (but also high returns on investment over time).
- Need for reliable volumes and consistent (biological) qualities of fuel stocks.

Opportunities

- Policy and technology synergies with decarbonising transport – e.g. converting fleets to biopropane / biogas.
- BioLPG is a technologically simple, familiar, and low-cost option for converting households away from oil boilers for central heating.
- Opportunity to address Scotland’s waste capacity gap - Scotland produces 1.35 million tonnes per year of food and drink waste - more food and organic waste can be diverted to anaerobic fermentation for biogas production.

- Potential to generate new skilled employment opportunities in rural and remote areas.
- Applications beyond heating – e.g. thermal hydrolysis for waste water treatment, biopropane production for fuelling space technologies.

Threats

- Need for long-term policy signals, planning and investment.
- Policy support needs to cross multiple policy silos – energy, waste, etc.
- Policies to eliminate the use of fossil LPG gas need to be sensitive to the potential unintended consequence of restricting the use of bioLPG, e.g. by restricting new connections and/or banning sales of gas boilers, central heating systems that can use non-fossil gas.
- Poor public perception of energy from waste plants

Sources: Abbess, 2019; Advanced Plasma Power, n.d.; Belshaw et al., n.d.; Calor, 2018; EST, 2017; Gallacher, 2019; SEPA, 2015 & 2018; United Utilities, 2019; Upham & Shackley, 2007.

3.5.1 Energy from Waste

Energy from waste (EfW) is a catch-all term that can, according to how figures are reported, encompass a wide range of technologies and fuel stocks. In its simplest form, EfW plants gasify waste or burn it in conventional combined heat and power (CHP) boilers to produce heat and electricity. Public perception of these plants, which are commonly grouped with other forms of incineration, is notoriously negative, and often with good reason due to their local impacts (Upham & Shackley, 2007).

Table 6, although containing older figures than reported elsewhere in this report, illustrates the costs and savings from waste heat recovery, energy from waste, biomass, and anaerobic digestion technologies connected to district heating networks at different scales, along with comparable figures for the four most common standalone renewable and low carbon heating energy technologies. It shows that, even as far back as 2009, the energy costs of recycling waste heat made it one of the most cost-effective options for providing heat, competing with solar thermal and natural gas. Biomass generally competes well with the others but doesn't excel either for providing low cost heat or reducing emissions. Energy from waste is costly and also fails to excel on carbon savings, although it is important to note that the technology has advanced and diversified since these figures were published, meaning we would expect current comparable figures to be somewhat more favourable. However, the important take-home message here is on anaerobic digestion, as the figures reinforce other evidence for this being a high cost but high return option.

Table 6. Cost of heat and emissions savings for different technologies, 2009

Technologies and Network Sizes	£/MWh of heat	Carbon savings compared to the baseline (kgCO2 per year)
Baseline cost (gas boilers and electric heating)	70	0
Standalone renewable and low carbon energy technologies		
Solar thermal	80	400
Air source heat pumps	115	-100
Ground source heat pumps	125	450
Individual biomass boilers	130	2600
Small scale district heating networks		
Anaerobic digestion CHP	245	5100
Community boiler biomass	115	2600
Community boiler natural gas	100	100
Small engine natural gas CHP	120	1000
Small biomass air turbine CHP	150	3600

Medium-scale district heating networks		
Medium biomass steam turbine CHP	125	3100
Large engine natural gas CHP	105	1600
Large scale district heating networks		
Waste heat	90	1800
Large biomass steam turbine CHP	120	3700
Energy from waste incineration CHP	205	2900
Medium CCGT natural gas CHP	110	2300
Small CCGT natural gas CHP	115	2000

Source: Pöyry, Faber Maunsell & AECOM, 2009

Notes: Figures are for 2009. Costs based on an average/composite UK dwelling based on the composition of the UK's housing stock. Figures do not account for effective cost savings, e.g. where old systems have to be replaced as part of general maintenance.

Energy from waste contributed a mere 5% to renewable heat capacity in 2016, over 80% of which was from 'advanced conversion technologies' (including anaerobic digestion CHP and heat as well as biomethane to grid technologies) (EST, 2017), and as six of the Scottish plants are listed as using municipal waste, whilst five are listed as using biomass (SEPA, 2018).

Conventional EfW technologies are a least-worst option for dealing with Scotland's capacity cap for managing municipal solid waste (MSW) (Gallacher, 2019), particularly in areas where the financial and emissions costs of transporting MSW to the nearest alternative treatment facilities are highest. For example, Orkney ships waste to fuel the EfW plant supplying energy for Lerwick's heat network; however, the council reports that it is now economically viable to manage this waste locally (Fraser, 2019). The general finding here, supported by a recent study at Glasgow Caledonian University, is that such conventional EfW plants will have a niche but nonetheless important role in decarbonising Scottish energy supplies (Quinn, M., 2019).

An alternative, and more flexible, way of generating energy from waste is to covert it into a gas, using any of a number of technologies, or combinations of them. These gas products can then be either piped into (suitable) gas network infrastructure, used to supply energy for district heating systems, or decanted into canisters as an alternative to fossil liquid petroleum gas (LPG).

3.5.2 Syngas

Syngas can be produced by the thermochemical treatment of waste at a lower temperature than required for gasification (commonly termed pyrolysis) to produce synthetic methane, to which carbon dioxide and hydrogen are added to produce specific mixes, and biogases can be added to reduce the carbon intensity of the mix. As for the production of any fuel requiring significant use of electricity, the emissions costs and savings from using syngas are heavily dependent on the grid electricity mix at any given scale (i.e. local, Scotland, or UK) (Abbess, 2019).

3.5.3 Biogas and Anaerobic digestion

The term biogas includes any gas mixes produced wholly or largely from the digestion of biomass by bacteria, most commonly using anaerobic digestion or fermentation to produce a methane-rich gas mix. Feedstocks can range from purpose-grown energy crops, which offer a high biological quality and consistency and a higher efficiency of conversion, to using municipal waste, which trades these benefits off against greater availability and lower costs of fuel stocks, and the cost and emissions savings from diverting waste away from landfills and incineration. Injecting biohydrogen or the hydrogen from gasification into the reactors during anaerobic digestion of biomass/waste can increase the methane content of the output biogas (Abbess, 2019). However, the utilisation of biogas in Scotland is currently very limited, and despite evidence for the potential of anaerobic digestion its contribution is so small that SEPA figures group recycling of waste by composting and anaerobic digestion (SEPA, 2015).

Nevertheless, some progress is being made, with Scottish Water having installed a state-of-the-art anaerobic digestion facility at their Deerdykes organics recycling site, outside Cumbernauld. This fully enclosed, modern facility enables

30,000 tonnes of food waste to be recycled each year (Abbess, 2019; Scottish Water, 2016).

3.5.4 BioLPG and Biopropane

One of the secondary aims of this report was to consider, specifically, the potential for biopropane as a heating option for off-gas and fuel poor households. Although the relatively new nature of the technology means few of our consultees were able to comment on the technical details, the production and use of biological alternatives to fossil LPG was generally seen as an attractive option, particularly for the Orkney islands which is seeking to treat its waste locally and has been piloting numerous energy generation and storage technologies as part of its efforts to tackle fuel poverty (Fraser, 2019).

BioLPG/biopropane can be used to replace natural gas in conventional gas-fuelled central heating, and so eliminates the capital costs of replacing boilers, pipes, tanks and radiators unless these are already needed as part of periodic maintenance. Such systems are also compatible with solar thermal, can be used to fuel LPG hybrid heat pumps, and with best practice insulation upgrades and energy management has been calculated to save an average householder ~£750 per year on their heating bills (Advanced Plasma Power, n.d.).

Figures supplied by Calor as part of this study show that bioLPG produced from waste is expected to have a similar (marginally lower) cost compared to fossil LPG, and is around 25% cheaper than using heat pumps. Compared to fossil LPG, for which the greenhouse gas emissions were calculated as 241 kgCO2eq/MWh, the emissions from bioLPG produced by a ‘first of a kind’ plant were calculated as being 51.9 kgCO2eq/MWh, a saving of 78%, with later generation plants expected to yield further performance improvements as evidence from operational use leads to greater process efficiencies.

Figure 11 gives the levellised capital and operational costs for decarbonising a typical rural off-gas grid house using bioLPG compared to other common technology options, and shows that the operational costs for both bioLPG boilers and hybrid heat pumps are closely competitive with other technologies (aside from electric heating, which has a significantly higher cost), and that the capital costs of LPG boilers are the lowest, and those for bioLPG heat pumps are notably lower than for ASHPs and biomass boilers.

The direct compatibility with fossil LPG boilers raises the need for future policies to eliminate the use of fossil gas to be sensitive to the potential unintended consequence of restricting the use of bioLPG, for example by banning technologically-identical LPG boilers. A more appropriate option may be to ban the sale of fossil LPG, given that bioLPG can be used as a direct replacement for any existing LPG technology. Furthermore, the Committee on Climate Change’s ‘Net Zero’ report identifies a small but significant number of homes that may still be reliant on fossil fuel heating by 2050, yet bioLPG offers a technologically simple, familiar, and low-cost option for decarbonising those households today.

3.5.5 Thermal Hydrolysis

Finally, it would be an omission not to note the potential, albeit site-specific potential, of using thermal hydrolysis to generate electricity as part of waste water treatment, with associated potential for generating biogas. Due to this site-specific limitation and the bias towards generating electricity it is beyond the scope of this report to comment in detail on the potential contribution of this technology to meeting the energy needs of off-gas households. However, we would draw particular attention to United Utilities’ pioneering thermal hydrolysis plant at Davyhulme, near Widnes, and more recently Severn Trent Water’s development of a plant at Minworth in the West Midlands (McNeill & Thornton, 2011; Severn Trent Water, 2016).

3.6 Heat pumps – Domestic air source heat pumps, domestic ground source heat pumps, and alternative community-scale technologies

Strengths

- ASHPS can be combined with solar photovoltaics to eliminate operational emissions.

- Easy to control – so particularly attractive for elderly / vulnerable / disabled householders.

Weaknesses

- Emissions performance is entirely reliant on the grid electricity mix unless combined with local renewables.
- May require significant interventions to improve the air-tightness of existing properties.
- Efficiencies and potential of ASHPS in Scotland have been over-estimated. GSHPs are a highly site and dwelling-specific solution.
- GSHPs have high upfront costs and comparably long payback periods for householders. Installation of GSHPs involves significant disruption to householders.
- Cost and availability of replacement parts in remote areas.

Opportunities

- Greatest benefits likely when applied to properties with higher levels of air-tightness and insulation.
- Tapping alternative renewable heat supplies, e.g. flooded mineworkngs and underground transport infrastructure.

Threats

- New generation ASHPs not accurately modelled in SAP.
- Alternative/community scale technologies require long-term investment and planning.
- The use of fossil gas for fuelling hybrid heat pumps will need to be eliminated as part of meeting emissions reduction targets.

Sources: Baster, 2011; BEIS, 2016; BGS, 2013; Ecuity Consulting, 2019; Committee on Climate Change, 2019; Church, 2012; Currie, 2016; Element Energy, 2017; EST, 2010; Fraser, 2019; Greenmatch, 2018; Mould, 2019; O'Donnell, 2019; Olivier, 2019b; Pöyry, Faber Maunsell & AECOM, 2009; WPZ, 2011.

3.6.1 Air Source Heat Pumps

Air source heat pumps (ASHPs), especially those with high efficiency factors and integrated solar photovoltaics, are a relatively attractive option for householders looking for flexible heating systems. As part of the research conducted for this report Hebridean Housing Partnership reported high levels of occupant satisfaction from installing 717 ASHPs (to date) into their housing stock. The housing association aims to give its tenants easy access to heat 24/7, and the systems require just three buttons to operate. Their main problem has been the treatment of their ASHPs (a Mitsubishi™ product) under the Standard Assessment Procedure, which requires an adjustment to the model to be applied in this case that, they report, is frequently not applied by assessors and results in properties being assessed as having SP scores under 65 (meaning installs fail EESSH requirements) (O'Donnell, 2019). An additional problem found with using ASHPs, mentioned by Orkney Islands Council, is the cost and availability of replacement parts in remote areas (Fraser, 2019), and ASHPs have been criticised for their visual impact when retrofitted to traditional Scottish housing (Baker, 2019).

However, whilst the local circumstances of the Hebrides (high exposure, high potential for generating renewable energy, population and tenant characteristics, etc) may well mean this story could be replicated in similar areas of the country, the figures provided in the Scottish Government's Second Report on Proposals and Policies (RPP2) and related documents suggest that it over-estimated the potential of ASHPs (Scottish Government, 2013a). One likely source of this error may be the coefficients of performance (COPs) quoted by David MacKay in his ground-breaking book 'Sustainable Energy without the Hot Air', which quoted coefficients of performance of 4.9 and 6.6 for Japanese models (Mackay, 2009). In reality, the COPs for ASHPs in the UK have been found to be highly variable, and despite their apparent political popularity the numbers installed to date have been far from inspiring. At the time RPP2 was published COPs were being reported as around half of Mackay's figures (Baster, 2011; EST, 2010; WPZ, 2011), and a recent Scottish study on two older off-gas social housing properties in Ayrshire found average annual COPs as low as 2.6 and 2.1 (Currie, 2016). However, the technology has since entered a new generation and the latest average UK figures we found quoted being between 3.0 and 4.3 (Greenmatch, 2018).

However, there is some more promising evidence for the potential of exhaust ASHPs, which are a specific variation of ASHP where the entire system is within the properties. Extraction from wet rooms (bathroom and kitchen) collects the heat and transfer it a to wet radiator system, with the excess moisture condensed into a drain. These systems are set up to sustain a steady state, therefore in the summer they can draw cooler external air from the north of a building to provide cooling. In addition to the steady temperature these systems have the benefit of air conditioning, reduce the moisture load and improve the indoor air quality. This can have health benefits to vulnerable householders with mobility and respiratory ailments (Mould, 2019).

3.6.2 Ground Source Heat Pumps

A 2012 analysis of (modelled) data from the Scottish Government pointed to the benefits of GSHPs if installed in timber frame homes constructed after 1982, with 2,776kgCO2 saved per year across this housing stock, at a cost of £10,000 per household. These figures increased to 3,758 kgCO2 at a cost of £18,620 per household when loft insulation, low energy lighting, and solar PV panels were added to the installation package, despite the cost of saving one tonne of carbon, rising from £10 to £34 the payback period (under 2012 conditions) increased marginally from 33 to 38 years (Baker et al., 2012). The cost used for installing a GSHP concurs with a current figure for Sweden (Olivier, 2019b). However, it is worth noting the evidence from the introductory section to this review of technology reviews which suggests that system sizes, and resulting costs, may be being under-estimated, particularly for larger properties (which are more common in rural areas) (BEIS, 2018; Scottish Government, 2019c).

3.6.3 Hybrid heat pumps

Hybrid heat pumps (HHPs), which combine a mains gas or LPG boiler with an air, water or ground source heat pump, have emerged as a politically popular technology option due to their competitive costs and compatibility with existing heating systems and energy infrastructure (BEIS, 2016, Committee on Climate Change, 2018; Scottish Government, 2019h). HHPs currently offer upfront cost savings of £450-£2,800 compared to a standalone heat pump for a typical semi-detached house; however, for highly efficient new build dwellings HHPs may not bring upfront cost savings over standalone heat pumps (Element Energy, 2017).

Hybrid heat pumps represent somewhat of a dilemma for policymakers, in that the potential for adoption by households on the gas grid will ultimately be limited when connections to new build dwellings are banned (assuming the Scottish Government follows Westminster on this) (Harrabin, 2019). However, when combined with bioLPG boilers they are currently a competitive retrofit option for decarbonising off-gas dwellings (Ecuity Consulting, 2019). They also have the potential to be used as back-up supplies to supplement other systems (e.g. solar thermal) but the cost effectiveness of using them in this way will decrease as the efficiencies and capacities of those systems increase. Therefore, the future uptake of HHPs will at least partially depend on whether the industry sees enough of a future market to justify continued investment in developing the technology to ensure the efficiencies and costs remain competitive as the scope of that potential market becomes more limited.

Also, as noted in Section 3.5.4 on bioLPG boilers, off-gas grid installations risk being limited if future policies are not sensitive enough to technologies for which bioLPG can be used as a direct replacement for fossil LPG. Finally, as an emergent technology we would note the evidence for other heat pumps that suggests the system sizes needed to fully replace existing heating systems have been previously underestimated, meaning we are not confident about the currently reported costs, particularly for typical rural properties. However, this mismatch also presents an opportunity for hybrid heating systems, which combine small electric ASHPs with gas boilers and use smart technology to automatically switch the output from one to another. This means the ASHP can make use of cheap and renewable electricity at times of peak availability, and switch to gas at times of peak electricity demand and contributions from fossil fuel generators (Calder, 2018). Replacing the fossil gas component of these systems with biopropane/bioLPG would then further decarbonise the heat supply, and this impact would be greatest at the times when the demand for heat is highest.

3.6.4 Alternative and community-scale heat pump technologies

At a community scale, the use of heat pumps, including the connection of heat supplies to district heating, has significant potential, albeit on a highly site-specific basis. The extraction of heat from large water bodies is already an established technology option, and such a system is being developed at Clydeport (Queens Quay, 2019). Whilst at Shettleston, an existing project pioneering the use of GSHPs to extract heat from the flooded mine-workings beneath the housing development, designed by John Gilbert Architects, is now being developed further in Glasgow as part of a ground-breaking project that could meet 40 percent of the city's heating demand (BGS, 2013; Church, 2012). This and other projects are also beginning to tap the potential from other abandoned subterranean infrastructure such as disused rail tunnels and sewers (New Scientist, 2013), and similar work is underway to tap deep geothermal (AECOM, 2013; Scottish Government, 2013b). These examples are far from exhaustive but it is beyond the scope of this paper to provide a full review of all such projects.

3.7 Hydrogen

Strengths

- Familiar heating technology – replacing natural gas boilers with hydrogen ones.
- Can aid air quality planning as emissions and pollution sources are highly centralised.

Weaknesses

- High fuel costs to householders.
- Impacts on primary energy supplies – increase in overall consumption, and increase in electricity grid emissions if this cannot be met by renewables.
- Requires large-scale use of CCS to be viable, and could lock Scotland into using natural gas well beyond national / international decarbonisation targets.

Opportunities

- More likely to compete for fuel for transportation and energy storage for grid balancing.
- Some applications being considered in specific locations (e.g. islands with excess supplies of renewables) but will compete with alternatives there.

Threats

- Limited savings to householders compared to competing non-electric options.
- Retrofitting homes for hydrogen presents new (and perceived) risks – risk of a negative public reaction.

Sources: Abbess, 2019; Committee on Climate Change, 2018; EMEC, n.d.; Energy Research Partnership, 2016; Frerk & MacLean, 2017; Leeds City Gate, 2016; O'Donnell, 2019; Smith, 2019.

Hydrogen can be produced in number of ways that can be split into processes that rely on the electrolysis of water, those which produce it from gasification of biomass and waste, those which produce it from biological sources, and those which use combinations of these, the former being the most common and conventional method of producing 'green hydrogen' (that does not use fossil gas), and one of the main 'power-to-gas' suite of technology options. Electrolytic hydrogen has the benefit of using a limitless supply of material (water), but at a significant cost to electricity demand. Synthetic hydrogen production relies on the gasification of biomass and waste (but can include an electrolytic component to supplement output), and again has a significant cost to electricity demand, as well as requiring consistent volumes and biological qualities of fuel stock. Biohydrogen is produced from the fermentation of biomass, and so is also dependent on the availability of fuel stocks. Finally, electrolytic hydrogen can also be converted into methane by combining it with carbon dioxide from a biomass origin (e.g. from gasification) to produce what is termed 'renewable methane' (Abbess, 2019). However, the poor energy density of biohydrogen makes it unsuitable for heating off-gas households (Advanced Plasma Power, n.d.).

Of all the technologies and fuel types reviewed as part of this study, the evidence on hydrogen was found to be by far the most uncertain in terms of its future costs, savings and impacts. The most significant risk to the future use of hydrogen, which is consistently acknowledged by those with more favourable opinions and raised as a key criticism by those with more sceptical views, is the need for carbon capture and storage (CCS) to be developed and installed at sufficient scale to make the large scale production of (non-biological) hydrogen economically viable (but not necessarily competitive).

Whilst it is beyond the scope of this report to cover CCS in detail it would be a major omission not to note the significant concerns and uncertainties around the development and deployment of the technology. To date, progress on CCS has invariably tended towards the most pessimistic predictions for its future, with the pilot plant at Longannet scrapped back in 2011 and Norway scrapping plans for two of three proposed plants in 2018 (Gas Strategies, 2018). Numerous concerns have been raised as regards the future costs of CCS and the volumes of waste carbon dioxide that will need to be captured and stored long-term, and the impacts these costs will have on future electricity prices (for example: Bullis, 2013; Heffron & Nuttall, 2017; Smith, 2019; Supekar & Skerlos, 2015; Wood et al., 2019). Similarly, one of our consultees commented that another future technology touted for decarbonising hydrogen supplies, direct solar photolysis of water, has been worked on for decades without any breakthroughs (Olivier, 2019a).

This means that if Scotland were to embark on a technological trajectory based around a significant expansion of hydrogen production it would be open to a significant and critical risk to its climate change targets if CCS deployment continues to track towards the least favourable projections, and even if these are exceeded the economic costs, and costs to householders, are still likely to be higher and more uncertain than for other technology options. And if CCS deployment can be accelerated to meet the capacity needed as we move towards 2030, the output from large scale renewable electricity generation needed to operate the technology and produce hydrogen will need to accelerate at an equal rate or greater rate, even before accounting for increasing demands from electric heating and electric vehicles. Otherwise extensive use of hydrogen risks relying on natural gas until late into this century, which would impact significantly on its emissions reduction targets and eliminate any ambitions for Scotland to become fossil fuel-free (Energy Research Partnership, 2016).

Furthermore, CCS also adds costs to householders by doubling to tripling the costs to hydrogen production (Smith, 2019). This is illustrated by the results of a recent project which modelled the costs and savings for developing hydrogen heating in Leeds, which found that by 2052/53 householders would save £39 on an average annual gas bill of £750, or £118 “If further home efficiencies were implemented” (Leeds City Gate, 2016).

Lesser risks to hydrogen development include the assumption that demand for hydrogen boilers will be sufficient for manufacturers to invest in their development (although the technological similarity to conventional gas boilers should offset this to some extent); the risk of low uptake due to public perceptions of hydrogen as an explosive fuel; and other competing technologies (e.g. biomethane and biopropane) being or becoming more cost effective for heating homes and reducing emissions.

However, despite these many criticisms it is also important to note that hydrogen may have significant potential in island areas of Scotland, where large amounts of renewable electricity can be generated and stored locally, and where grid capacity is insufficient for exporting this directly to the mainland grid. This was reflected in support for the technology from the consultees in the Hebrides and Orkney Isles (Fraser, 2019; O’Donnell, 2019).

As such, the question of whether, and to what extent hydrogen should form part of Scotland’s future energy mix is as much a political one as a technological one. On the mainland, there is a clear case against developing hydrogen simply due to the substantial and highly significant risks associated with its development and deployment. Yet, in the absence of sufficient commitments to substantially upgrade the electricity connections to the islands there is a case for its potential to meet the needs of householders in these areas. However, the necessary reliance on CCS to decarbonise electrolytic hydrogen dictates that either the development of hydrogen in the islands be limited to biological hydrogen (with its own associated limitations) unless CCS can be developed and deployed at a sufficient (nationwide) scale for the necessary economies of scale to make it economically viable amongst these small populations.

3.8 Wood fuel biomass

Strengths
— Familiarity, scalability, and flexibility of the fuel and technology options. — Appropriateness for Scotland of developing and using local fuel supplies. — Established technology that can be used as a direct replacement for gas.
Weaknesses
— Concerns over the sustainability of imported wood fuel supplies. — Air quality impacts – the use of individual biomass boilers and CHP systems is regulated in urban areas. — Impacts of transporting large volumes of fuel.
Opportunities
— Significant potential when used as part of multi-technology district heating networks. — Significant potential to develop local fuel supply chains and leverage associated co-benefits in rural areas.
Threats
— Low afforestation rate in Scotland. — The Renewable Heat Incentive is due to end in 2021. — The future trajectory of support for sustainable biomass is currently uncertain.

Sources: Baker, 2017; Forestry Commission, 2017; Pridmore et al., 2017; SEPA, 2010; SNH, 2017.

Wood fuel biomass is covered separately here due to its uses as fuel for both small-scale systems, e.g. individual domestic systems, and large-scale systems, e.g. combined heat and power (CHP) plants feeding district heating systems. For the purposes of this report we are defining wood fuel in the broader sense of both purpose-grown fuels and waste/bi-products from other forestry and woodland products and land management. This is in order to acknowledge and draw attention to the evidence that the latter becomes economically viable, and indeed competitive, when sourced locally (Ricardo Energy & Environment, 2019).

Individual biomass boilers and CHP systems have proven an attractive medium-cost heating solution for those householders able and willing to adopt them, with Citizens Advice reporting the costs of replacing a solid fuel back boiler heating system with a biomass boiler as being between £10,000 and £15,000 (Citizens Advice Scotland, 2016). In many rural households wood fuel and/or solid fuel options form part of a mix of heating technologies. For example, homes with storage heaters and open fires or with back boilers and plug in electrical. We have previously found that rural homes may have multiple combinations of technologies and as such our current national data does not wholly account for or describe reliably, the level and condition of rural fuel poor households (Baker et al., 2016). As regards the use of individual biomass boilers in off-gas urban areas, it is important to note that the density of Scottish towns and cities and the 'canyoning' effects created by long rows of tenements that funnel pollution through streets and public spaces means these are tightly regulated in urban areas (SEPA, 2010).

However, there are significant concerns over the current and future sustainability of Scottish biomass fuel supplies, particularly imported supplies of wood fuels (Baker, 2017), and despite having set a target of reforesting 21% of Scotland by 2032 progress is running far behind the rate needed to achieve this – the afforestation rate is currently 4,800 hectares per year and needs to reach 15,000 hectares per year by 2024 (Forestry Commission, 2017; SNH, 2017). Anaerobic digestion can be used to support this demand; however, the wider benefits (co-benefits) of developing local, sustainable biomass fuel sources that are also managed for construction products, recreation, tourism, and biodiversity would be significant. This would also have the additional benefit of providing employment and supporting regeneration in many deprived areas, and those where the decline of the fossil fuel industry will lead to job losses (Pridmore et al., 2017). Common Weal has previously set out its proposals for how Scotland's barren grouse moors, which consume almost a fifth of the country's land area, could be repurposed to generate substantial new employment opportunities by providing land for renewable energy, biomass, forestry, agriculture, horticulture and housing in our 'Back to Life' report (Common Weal, Lateral North and the Revive Coalition, 2018).

Therefore, whilst we are able to conclude that the benefits and potential of sustainable, locally-sourced wood fuel biomass for meeting the heating needs of off-gas households and tackling fuel poverty are substantial and significant, this potential cannot be unlocked without legislation that considers and supports the whole fuel production and supply chain. This is covered in more detail in our separate report on defining successful district heating systems in Scotland (Baker & Mould, 2019).

3.9 Technology and fuel options: Key findings

From reviewing the evidence gathered for this review of technology and fuel options for off-gas households in Scotland we are able to reach a number of key findings:

- The conversion of households to electric heating systems is likely to remain a common technology option, but this would be at the expense of higher heating costs to householders, locking emissions savings to those of the electricity grid mix, and generating increasing demand for renewable electricity that will compete with other increasing demands, primarily for electric vehicles. This raises the question of how the Scottish Government should treat operational costs to householders relative to capital costs of installation to both householders and publicly-funded energy efficiency and fuel poverty programmes.
- The potential of building-mounted solar thermal remains woefully unexploited in Scotland, and whilst the technology is generally unable to meet the total heating needs of an average household it is a highly effective solution for reducing heating costs and emissions, and tackling fuel poverty, particularly when combined with other appropriate technologies.
- The proven 'Danish model' of district heating, which combines large-scale solar thermal and inter-seasonal heat storage with heat recovery and biomass fuels has, to date, been completely overlooked by the Scottish Government, which we would suggest is at least partly due to the silosation of policymaking. This solution, if supported by policies to support the development of whole fuel supply chains (for wood fuel biomass and biogases), has the potential to supply significant numbers of properties with renewable and low carbon heating, as well as unlocking substantial co-benefits to householders in deprived rural and island areas. We are of the view that the lack of consideration of this model is a critical failing of current Scottish energy policy.
- Conventional energy-from-waste technologies should be expected to play a niche but key role in decarbonising domestic heat supplies. However, there is substantial and significant unlocked potential to develop low carbon biomass fuels and technologies, particularly anaerobic digestion, biopropane and biomethane. Such solutions also have significant potential for closing Scotland's waste management capacity gap. Whilst we have serious concerns over the true sustainability of imported biomass wood fuel supplies, we are strongly of the view that much more could, and should, be done to develop and utilise local supplies of wood fuels.
- Whilst we are of the view that heat pumps have demonstrable benefits for meeting

the heating needs of off-gas householders, we are of the view that the potential of these technologies has generally been overestimated. This is primarily due to the evidence on actual costs of installed systems and the associated emissions savings (including locking these savings to the grid electricity mix), and the site-specific nature of the potential of non-air-source heat pumps.

— The development of electrolytic hydrogen as a heating solution is open to significant and potentially critical uncertainties over future costs, emissions savings, and the associated (and necessary) development of carbon capture and storage (CCS). A key exception here is for island areas where unexportable renewable electricity can be used to power electrolysers. However, in that case any proposals for developing hydrogen in these areas should account for the likelihood of upgrading connectors to the islands as part of wider (and non-devolved) energy policy. We are not currently of the view that biohydrogen is an appropriate option for heating off-gas households due both to its low energy density, and the more competitive costs and emissions performances (and co-benefits) of other biological fuel supplies (e.g. biopropane, biomethane, and wood fuel biomass).

4: ENABLING ALTERNATIVE HEATING SYSTEMS IN OFF-GAS AREAS

This section of this paper brings together evidence from the previous sections and the views expressed by our consultees to summarise our findings on how to enable householders in off-gas areas to adopt alternative renewable and low carbon heating technologies and fuels, and the current barriers to and opportunities of meeting this and related Scottish Government policy objectives.

A recent report by Ramboll on alternative heating systems for the Department for Business, Energy and Industrial Strategy (BEIS) (Ramboll, 2019) includes a number of findings that are particularly relevant to this objective. The study considers four alternative scenarios for converting a typical small to medium sized town in the UK to low carbon heating: hydrogen (with CCS); hybrid heat pumps; electric heat pumps (a mix of GHSPs and ASHPs); and DHS using biomass and water source heat pumps. As regards off-gas households, the key points to note are as follows:

— The hybrid heat pump scenario performs the best in terms of lifecycle net present costs (NPC) and carbon reduction costs, but is obviously not an option for off-gas households, and locks in a long-term reliance on using of natural gas.

— The hydrogen scenario offers the greatest CO2 reduction potential, but of the four scenarios it is open to the greatest range and number of uncertainties, including technology and energy costs, assumptions made from a limited number of studies, the assumption that manufacturers will develop hydrogen boiler systems, and significant uncertainties as regards the costs and performance of CCS, which is yet to be proven or deployed at a useful scale.

— The electric heat pump scenario generally performs weakest across the board however, under a low temperature scenario (assuming additional investment in energy efficiency and the adoption of low temperature heating systems) the technology choice becomes much more favourable, offering a lower lifecycle NPC than hydrogen or DHS.

— The DHS scenario performs well overall but is open to greater uncertainty than the two heat pump scenarios as regards fuel costs. However, the technology choice (using a water-source heat pump) is a relatively unusual and site-specific combination, and our evidence on the Danish multi-technology model leads us to the view that this would perform (potentially much) more favourably if modelled under the same conditions.

The evidence presented in this report is largely commensurate with our own findings and demonstrates the necessity of engaging specialist engineering expertise as part of policy development, something we have consistently recommended in our responses to Scottish Government consultations and calls for evidence (Energy Poverty Research initiative, 2017-2019). The Scottish Government's current call for evidence on the future of low carbon heat for off-gas buildings identifies a number of barriers to the uptake of renewable and low carbon heating (Scottish Government, 2019h). These are listed here along with short responses based on our findings from this research, which are developed further in our conclusions and recommendations.

Lack of consumer and supply-chain knowledge of low carbon heat technologies

Our evidence leads us, in most cases, to dispute this broad-brush assumption of a lack of consumer awareness. Whilst this has indeed been identified as one of a number of barriers to the deployment of low carbon heating (e.g. Chaudry et al., 2015) this barrier is likely, in part, to result from the diversity of householder needs and preferences and the appropriateness, or otherwise, of different technological options for meeting those needs and preferences (Energy Technologies Institute, 2015). Options such as electric heating, biomass boilers, and heat pumps are established technologies and substantial volumes of information and guidance are available to the public through agencies such as Citizens Advice Scotland, local authorities, housing associations, Community Energy Scotland, Changeworks, Warmworks, and Home Energy Scotland. However, our previous research has indicated that the pace at which heating technologies are evolving means that this information can quickly fall out of date (Atterson et al., 2018).

As such, the logistics of the problem of keeping such substantial volumes of information up to date indicate that the problem should be better reframed as the need for those advising householders to fully understand their individual circumstances, needs and preferences, and to have the expertise needed to identify the most appropriate solution(s) for them. In the case of fuel poor and otherwise vulnerable householders such solutions are unlikely to be limited to technological fixes, and hence the need for a shift in policy from delivering 'fabric first' to delivering 'folk first' solutions (Baker et al., 2018 & 2019b). As regards supply chain knowledge, we are of the view that this problem is much more due to a lack of knowledge on the part of the Scottish Government and its delivery bodies than on the part of suppliers.

The use of locally-sourced sustainable biomass is being hindered by a lack of development of local markets, the production of biomass (e.g. forest residues), and the development of transport infrastructure and long-distance logistics, which are fundamental to the success of a supply chain. These could be overcome by end-users taking more control of the supply chain and in diversifying supply across regions (Ricardo Energy and Environment, 2019).

The relatively high upfront costs of installing low carbon heating systems, relative to like-for-like replacement of incumbent systems

Whilst we would agree that some replacement systems and fuels, notably hydrogen and larger capacity heat pumps, incur high relative costs we would dispute the apparent assumption that this barrier applies to all alternative technology and fuel types, notably solar thermal. Furthermore, the higher up-front costs of a number of technologies with significant potential to provide low cost and/or low carbon heating with strong returns on investment (in terms of financial benefits, emissions reduction benefits, and co-benefits) mean that their up-front costs should not be considered as a barrier to their development and deployment, specifically anaerobic digestion, biogas/biopropane, locally-sourced woodfuel biomass, and district heating systems based on the Danish model.

Where this issue becomes critical, as detailed in the recent review of EPCs (Alembic Research et al., 2019) is that the upfront capital costs of upgrading E to G rated homes, and particularly homes in rural and remote areas, will be impossible for householders and landlords to avoid if and when mandatory upgrading is introduced. In these cases, as highlighted by the consultation on EESSH2 (Scottish Government, 2018b), the technological solutions available for these homes may be very limited or not at all suitable for raising these properties to the minimum EPC rating (under the current methodology), and are likely to have (potentially prohibitively) long payback periods. And therefore the current proposals do not provide an equitable pathway for these householders and landlords to support the Scottish Government's ambitions for decarbonising domestic heating.

The disruption of upgrading and/or replacing the internal heat distribution systems so that they are compatible with low carbon technologies e.g. re-sizing radiators, installation of a wet central heating system

Whilst many of the technologies covered here do involve significant disruption this is another over-simplification. Disruption to householders is anyway caused by the need to periodically replace boiler systems, and such householders can be targeted for conversion to alternative fuels (e.g. biomass and biopropane) when boiler replacements become necessary. Connection to district heating systems is disruptive to householders however, deployment of DHS infrastructure is less disruptive in rural areas due to the lower density of existing hard-standing infrastructure (roads, paved areas, railway lines, etc). Assuming such disruption should be avoided would simply work to favour conversion to electric heating and the installation of air source heat pumps, which again risks exacerbating the energy equity gap between urban and rural householders as the latter become more at risk of being locked into paying significantly higher operational costs, and (depending on the rate of increase in renewable electricity supplies) generating higher emissions.

The need to dispose of heating systems components, in some cases prematurely, when switching to low carbon heat e.g. disposal of heating oil storage tanks

This is generally an unavoidable consequence of decarbonising domestic heat supplies. However, for some fuels (bioLPG, biopropane) it is possible to switch fuel supplies without replacing existing LPG boilers, storage tanks and piping, assuming they have been maintained to a sufficient standard.

Potentially higher operational and / or maintenance costs

This is true for some technologies and fuels, particularly electric heating and hydrogen. We would also note the issue of the availability of spare parts (e.g. for domestic heat pumps) in island and remote areas, as was raised by Orkney Islands Council as part of this research. A review of operational and capital costs of different technology options has been conducted as part of producing this paper.

Limited capacity in some locations on the electricity grid to supply substantial increases in electrical heating

This has consistently been noted as a key barrier by many stakeholders, including the two distribution network operators. The problem has arisen from a consistent lack of long-term thinking and policy and investment signals from the Scottish Government to the energy industry and other stakeholders. This is needed to, and should actively enable, the network operator(s) to invest in increased local grid capacity, storage, and management. We would draw attention to the Scottish Federation of Housing Associations' note that smart grids that enable householders to use electricity when it's better value (for example by the Smart Fintry project), and that the current structuring of the National Grid for centralised generation is a key barrier to enabling new infrastructure and alternative heating systems.

We would also draw attention to the circumstances of communities in areas where the potential renewable electricity generation capacity is high, but where the export capacity of the grid is currently constrained, and the different legislative options necessary and / or available for decarbonising heat and other energy supplies in these areas (see our Conclusions and Recommendations).

Lack of any regulatory requirement to install low carbon heating systems

This is indeed a barrier, and one which is almost entirely within the remit of Scottish Government to address through its own legislation and regulations (e.g. the Scottish

Building Standards). As part of this research Calor and SPEN specifically recommended setting dates for decarbonising heat supplies to off-gas households, by setting target dates for converting all households and / or by setting dates for a ban on the sales of all new oil and coal boilers (Calor, 2018; SPEN, 2019). This recommendation is supported by Common Weal and the Energy Poverty Research initiative and, in light of the recent findings by the Committee on Climate Change, we recommend that a ban on the sale of all new oil and coal boilers could reasonably be implemented alongside the introduction of the revised Scottish Building Standards in 2021. We also recommend a target of converting all existing off-gas households to renewable or low carbon heating by 2040.

The later target set for decarbonising all off-gas households reflects the need to ensure the technologies installed are long-term solutions that can deliver the greatest benefits and co-benefits to the environment, the economy and society. Whilst some technologies, particularly district heating, will require comparatively long lead-in times for planning, development and retrofitting, the greater issue here is the need to develop local and sustainable fuel supply chains, e.g. for biomass and bioLPG. This complex mix of policy and householder needs, and the range and mixes of technological solutions that may be appropriate for any individual household, building type, location, etc, mean that future policies will need to be flexible enough to ensure that unintended consequences, such as banning gas connections to households that may benefit most from technologies such as biogas and hybrid heat pumps, is avoided - whilst also rapidly managing the decline of fossil gas.

A further regulatory barrier is the lack of appropriate planning legislation to leverage the development of heat networks. We have long advocated the adoption of a Heat Supply Act based on the successful legislation that has been implemented by Denmark since 1979 (Baker et al., 2012; Baker, 2017; Danish Energy Agency, n.d.). A full discussion of the need for such an Act and how it should be designed and implemented is provided in our ‘Just Warmth’ policy paper on developing equitable and sustainable district heating (Baker & Mould, 2019). Due to the urgency of this need we recommend that such an Act should also be introduced alongside the 2021 revision of the Scottish Building Standards.

Public finance limits to the level of support that can be provided by government to incentivise uptake

Whilst we accept that this is a limitation, our evidence leads us to the view that the Scottish Government could be doing much more within these limits if this evidence was better understood by policymakers and politicians, and used to develop more appropriate and supportive legislation.

We would also draw attention to Common Weal’s proposals for a Scottish National Investment Bank and Scottish National Investment Company (Common Weal, 2017), the former of which has been taken up by the current SNP administration. We would strongly encourage the Scottish Government to explore how future funding available through the SNIB could be used to increase the level of financing available to incentivise off-gas householders to adopt renewable and low carbon heating systems, and to support the deployment of new energy infrastructure, generation, and storage, along with supporting the growth of the necessary fuel supply chains. In addition, our proposals for the Scottish National Energy Company and a Scottish Energy Development Agency would serve to provide a national reservoir of competence and expertise to catalyse the development and deployment of such new systems and supply chains (Baker et al., 2019a).

Low carbon heat technologies are not suitable for some energy intensive industrial processes

As the scope of the evidence presented here is largely limited to enabling low-carbon domestic heating we are unable to provide findings on heating non-domestic buildings. However, we would stress that this barrier is also an important argument for introducing legislation to require the recovery of waste heat from these sources and processes, as required by the Danish Heat Supply Act (see: Baker & Mould, 2019).

Other barriers not addressed in the Scottish Government's call for evidence on decarbonising heat supplies to off-gas households

Finally, as regards key issues for the development and deployment of renewable and low carbon heating technologies we would re-emphasise two key barriers not addressed in the current call for evidence:

— The Scottish Government's continued belief in the validity of using Energy Performance Certificates (as they are currently generated) to drive energy efficiency, fuel poverty, and emissions reduction policies is, in our view, by far the most substantial barrier to decarbonising the Scottish building stock. This view has been supported by the findings of the Scottish Government's recent review of EPCs (Alembic Research et al., 2019), and consistently supported by the evidence gathered for this paper and our other research activities. These criticisms and our proposals for an alternative approach to EPCs which would better meet the needs of both households and the European Union's requirements under the Energy Performance of Buildings Directive are covered in full in a previous policy paper (Baker & Mould, 2018).

— Finally, several consultees including the SFHA and Orkney Islands Council also made the point, which would be echoed by Common Weal and the Energy Poverty Research initiative, that EPCs and other Scottish energy and emissions reporting don't accurately reflect the grid electricity mix in Scotland, or indeed locally (in areas where excess renewable energy cannot be exported), as this figure is calculated at a UK level. Common Weal is naturally of the view that devolving the grid emissions factor would benefit Scotland.

5: CONCLUSIONS

Referring back to our original three research questions, the evidence reviewed for this paper leads us to draw the following summary conclusions:

What specific problems do the current and proposed regulatory regimes pose for these householders, what evidence is there for an energy inequity gap between these householders and others, and what effects will current proposals have on them in the future?

There is strong and robust evidence for the existence of this energy inequality gap. Households in rural and island areas spend proportionally more on energy for heating and, importantly, the distributions of household expenditure on heating are significantly different than for urban areas. Many households in rural and island areas live in off-gas properties and so risk being further disadvantaged if the costs of decarbonising heating fall disproportionately on off-gas households, and we are strongly of the view that this will happen under the Scottish Government's current proposals.

Of particular concern is the Scottish Government's continued belief in the validity of the method and modelling used to generate Energy Performance Certificates (EPCs), which serve to both disadvantage these householders and unnecessarily hinder the uptake of appropriate retrofit solutions for them. We note that the Scottish Government's own review of EPCs notes a substantial number of technical and procedural changes that would need to be made to address many of the ways in which an EPC-led regulatory regime would fail to meet the needs of these householders (Alembic Research et al., 2019), and have concerns over the costs and timescales needed to do so. We have previously published our proposals for an alternative approach to producing EPCs (Baker & Mould, 2019) and, should our concerns not be addressed, whilst we support the principle of mandating upgrades across all housing tenures, we have to oppose the proposals for this as they stand.

We are firmly of the view that, if current and future regulatory regimes continue to rely on EPCs as a driver for policy, then this inequity gap will be exacerbated in a number of ways, but primarily through driving off-gas householders either to convert to electric heating, with its high operational costs, or through driving them to spend proportionately more on the capital costs of installing alternative, sufficiently-sized, heating systems.

What is the potential for different forms of off-gas heating to meet the needs of these householders, whilst also meeting policy objectives for decarbonising Scotland's energy supplies? The technologies to be reviewed will be electric heating, bioLPG, hydrogen, solar thermal, biomass and biofuels, heat pumps, heat recovery and storage technologies, and combined heat and power (CHP). district heating systems (DHS).

It is not the intention of this paper to 'pick winners' and we strongly urge readers to ensure they read and understand the caveats to the evidence presented here. However, broadly, we are able to draw a number of summary conclusions as regards the potential of different technology options.

Firstly, we note that converting off-gas households to electric heating has a number of advantages, particularly the low costs of installation and familiarity to householders. However, electric heating systems incur operational costs that (with the probable exception of hydrogen) are significantly higher than all the other technologies considered here and that, particularly due to the inefficiencies of the systems, a substantial conversion of Scottish households to electric heating poses a significant risk to meeting Scotland's emissions reduction targets if the generation of renewable electricity cannot be ramped up at a rate that exceeds the resulting increase in demand, as well as meeting a significantly increased demand from electric vehicles. A further risk here is the impact on thermal generation if and when Scotland's remaining nuclear power plants are switched off after 2025 (a policy which we support). As we have discussed further in recent and forthcoming publications, we are of the view that there is a very real risk of these competing demands resulting in a 'perfect storm' for decarbonising Scotland's energy consumption in the mid to late 2020s.

As regards hydrogen, we note that, with a number of important caveats in relation to its development in grid-constrained island areas, there are significant and substantial risks to using policy to drive the uptake of hydrogen for domestic heating, and that these are distinct from the risks for other applications (e.g. for fuelling transport). As well as the substantial uncertainties over the effectiveness of hydrogen as a heating solution, the success or otherwise of any substantial adoption of electrolytic hydrogen is open to further significant risks from the future development, costs, and effectiveness of carbon capture and storage (CCS) technologies. Any substantial uptake of hydrogen as a heating solution would require a significant and costly ramping up of CCS deployment, and of the renewable electricity generation needed to power it. We are of the view that this is highly unlikely to be achieved either at sufficient scale and/or in sufficient time to mitigate the risk of locking Scotland into depending on fossil fuels long beyond any reasonable target for decarbonising its energy supplies. This does not preclude being able to recommend hydrogen in certain scenarios; however, it raises a challenge for ensuring equity across Scotland if the resulting increased electricity consumption in grid-constrained areas able to supply ~100% renewable electricity is not offset by a local grid emissions factor.

As regards the other technologies reviewed, and with the exception of building-mounted solar thermal, we note that these are broadly competitive, with different costs and benefits attributable in different circumstances, ranging from large-scale adoption to highly site-specific conditions. A general conclusion, particularly in relation to the adoption of heat pumps and biomass boilers by rural and off-gas households, is that previous assumptions about system efficiencies and the resulting figures for installation costs, mean that these have been underestimated. This should be borne in mind when considering their relative costs and benefits in relation to alternative technologies.

Evidence gathered for this and our supplementary paper on developing equitable and sustainable heat networks leads us strongly to the conclusion that the potential for developing district heating in many rural and island areas has been substantially underestimated, and even more so when the benefits and co-benefits of developing the necessary infrastructure and sustainable fuel supply chains are considered where they exist or can be developed. Critical to this is the evidence for the significant cost reductions and efficiency improvements attributable to the multi-technology ‘Danish model’ of combining large-scale solar thermal arrays with inter-seasonal heat storage technologies and one or more heat recovery, sustainable biomass, or energy from waste technologies. One likely reason for this is the assumed higher capital costs of deploying DHS in rural areas which, based on the most recent evidence available to us from operational systems, we find to be marginal, and more than offset by the additional benefits and co-benefits to communities in deprived rural and island areas. We have previously noted that this proven approach has been absent from Scottish Government thinking and are strongly of the view that supporting the development of such systems, and the associated supply chains, should be considered as a policy priority.

A key aim of this paper was to explore the potential for converting off-gas households to bioLPG and biopropane-based heating systems, and we feel the need to be clear that whilst Calor have provided evidence on this, our conclusions have not been influenced by their funding of this paper. The primary heating applications for these fuels being as direct replacements for fossil LPG, providing fuel for hybrid heat pumps, as a low-disruption option for replacing oil boilers and as a fuel supply option for multi-technology district heating. Based on the best evidence available to us, and with the caveats noted in the review of technologies, we are able to conclude that the adoption of bioLPG as a direct replacement fuel for fossil LPG boilers offers a number of clear benefits to householders, particularly the highly competitive operational costs, the lack of the need to replace existing heating systems (beyond normal replacement periods), and the familiarity of the technology to householders. We also note the important additional benefit of such systems being compatible with solar thermal and heat pumps. Whereas we are more sceptical of the potential of hybrid heat pumps in general, we note that fuelling HHPs with bioLPG/biopropane serves to mitigate the risks of these householders being locked into using fossil LPG. Finally, we are of the view that the scalability and costs of biopropane production, as well as its potential to support the mitigation of Scotland’s waste management gap, make it an attractive option as a fuel supply for sustainable district heating.

Finally, the most consistent evidence we reviewed was for building-mounted solar thermal heating systems. Whilst it is important to note that such systems would rarely be expected to meet one hundred percent of household heating demand, their consistently low costs of installation, operation and maintenance, as well as their familiarity to householders, make policies to support the ramping up of their adoption and deployment an easy win for tackling energy efficiency and fuel poverty.

What are the current and likely future barriers and opportunities as regarding the existing and proposed development of energy infrastructure for enabling alternative heating supplies in rural off-gas grid areas?

As noted previously, the Scottish Government’s continued belief in the validity of using Energy Performance Certificates, as they are currently produced, is a significant current and future barrier to the development and deployment of alternative heating systems in rural off-gas grid areas. Similarly, policy assumptions about the costs and efficiencies of deploying sustainable district heating in rural areas pose a key and significant barrier to this option for decarbonising off-gas households, and realising the associated benefits and co-benefits to communities in these areas.

In the future, increasing and competing demands for renewable electricity from all sectors of the economy, but particularly transport and the generation of alternative fuels, pose risks both to Scotland’s capacity to decarbonise heating supplies, and to meet its greenhouse gas emissions reduction targets, and particularly under the more ambitious trajectory recommended by the Committee on Climate Change.

As regards opportunities, we are of the view that these are most significant for the future development and deployment of solar thermal, biogases (including bioLPG, biopropane, and biomethane from anaerobic digestion), and combinations of these technologies, either at household level or when deployed as part of multi-technology district heating systems. We are also strongly of the view that the potential of heat storage technologies to enable solar thermal (at all scales) and district heating has been far from sufficiently recognised by the Scottish Government, and so presents an important technological opportunity that has yet to be exploited. Whilst a fully-costed environmental, social and economic assessment of all these options has yet to be conducted at a national scale (and we would welcome the commissioning of such an assessment) we are strongly of the view that the evidence to date is sufficient to recommend policies and supporting measures to significantly ramp up their development and deployment, along with the capacity of their relevant fuel supply chains.

6: RECOMMENDATIONS

Our findings and conclusions from this paper lead us to make the following recommendations:

- We recommend that a ban on the sale of all new oil and coal boilers be implemented alongside the introduction of the revised Scottish Building Standards in 2021.
- In order to develop the necessary infrastructure and fuel supply chains necessary to maximise the benefits of heat networks we recommend the urgent adoption of a Danish-style Heat Supply Act, which should also be introduced alongside the revised Scottish Building Standards in 2021.
- We recommend that the Scottish Government adopts a target for retrofitting all off-gas households with renewable or low carbon heating systems by 2040. We further recommend that interim targets are adopted (e.g. for 2025, 2030 and 2035) to ensure that, as has resulted from previous policies, ‘high hanging fruit’ such as the large-scale deployment of new energy infrastructure is prioritised for deployment as part of this energy transition.
- We recommend that the Scottish Government explores how future funding available through the Scottish National Investment Bank could be used to increase the level of financing available to incentivise off-gas householders to adopt renewable and low carbon heating systems, and to support the deployment of new energy infrastructure, generation, and storage, along with supporting the growth of the necessary fuel supply chains.
- We recommend that the Scottish Government develops and adopts proposals specifically to reverse its slow rate of progress on the deployment of solar thermal, both building mounted systems and large-scale arrays for supplying district heating. At a household level, installing solar thermal systems should be considered wherever technically feasible, and where other policy barriers exist (e.g. local conservation legislation), solar should be granted an automatic exemption from these.
- We recommend that the Scottish Government develops and adopts proposals specifically to leverage the uptake and capacity of thermal storage technologies in all their forms, at both domestic and community scales. At a domestic scale, the installation of heat batteries should be recommended (and incentivised) as an option wherever technically feasible.
- We recommend that the Scottish Government, in consultation with appropriate experts and stakeholders, conducts a full environmental, social and economic assessment of the costs, benefits, and co-benefits of those technologies found to have the greatest potential for meeting

the needs of rural, island and off-gas householders. However, and importantly, we further recommend that this is not used as a justification for developing and implementing policies to ramp up their installed capacity. This is due to both the urgency of the need to decarbonise the economy, and due to the lead-in times needed to plan and install the necessary infrastructure and technologies. We further recommend that, as part of this consultation and assessment, the Scottish Government ensures that policies do not introduce unintended consequences that could restrict the supply of biogas for conventional central heating systems and hybrid heat pumps, particularly for retrofitting homes currently using coal and oil boilers.

— We recommend that the Scottish Government obtains legally-binding confirmation of the specific plans, or otherwise, to increase the capacity of the connectors to electricity grid constrained areas, and then to consult with the relevant local authorities, industries, communities, and other stakeholders in these areas to determine the most beneficial options for decarbonising heat supplies in these areas. Following from this, if in future these areas are able to export increased amounts of renewable electricity to the grid, then new legislation should be introduced to ensure the profits from this accrue to the public sector and communities, rather than to private landowners. If this export capacity is not to be expanded it is likely to be necessary to include adjustments in future legislation to enable greater energy equity between these areas and the rest of the country. Although Scotland does not yet have a devolved grid emissions factor, a recommendation previously made by Common Weal and repeated again here, should this change under further devolution or independence, we would recommend a further devolution of the factor to reflect the circumstances of grid-constrained communities.

— We recommend that the Scottish Government secures an agreement with Ofgem that all regulatory levies be removed from households in remote areas where the electricity grid is constrained, unless and until that local constraint is removed. We also recommend that local authorities in grid constrained areas be given the necessary powers to implement moratoria on new private generators being allowed to export excess electricity beyond the local grid, and to set the prices for exporting to local grids (if such additional capacity is needed).

— In light of Scotland's waste management gap, we recommend that all future energy policies include a strategic consideration of areas where local waste sources could be converted to energy supplies (including bioLPG, biopropane, biomethane and direct conversion to heat) to meet heating demands in these areas. Such policies should also be periodically reviewed in order to capture future changes in local circumstances that may impact (positively or negatively) on the economic, social and environmental viability of the development and deployment of these technologies. In the specific case of 'waste' biomass from forestry and agriculture, there is a need for greater clarification and consistency in reporting the nature and availability of these supplies, which should also be cognisant of any environmental considerations over the removal of 'waste' biomass from these ecosystems.

— Following from this, we recommend that the Scottish Government considers the potential of managed rural landscapes, such as grouse moors, to be reclaimed for providing land for renewable energy, biomass, forestry, agriculture, horticulture and housing, and for generating new employment, regeneration and tourism opportunities in relation to these. Common Weal, along with Andy Wightman MSP and many others campaigning for land reform, has long argued that land reform should be considered an essential component of meeting the Scottish Government's climate change targets and its wider environmental, social and economic agendas.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest. Although this report was funded by a commercial company the authors received no direction beyond agreeing the scope of the questions to be addressed and agreeing the approach to the research. No limitations were placed on any aspects of the report, including the areas of research and the list of consultees. The findings and recommendations therefore represent the collective views of Common Weal and the Energy Poverty Research initiative.

LIST OF CONSULTEES

The Project Team would like to thank the following for their contributions to this report:

Bill Sheldrick, Alembic Research

Dave Andrews, Claverton Energy Research Group

David Olivier, Energy Advisory Associates

David Stewart and Sarah Boyack, Scottish Federation of Housing Associations

Dr Geoff Wood, University of Stirling / Palgrave Macmillan

George Goudsmit, AES Solar

Gordon Morgan, Common Weal Energy Working Group

Iain Wright, independent researcher / Common Weal Energy Working Group

Jo Abbess, GEDS Associate Research Fellow, Birkbeck, University of London

Kendal Adams and Graham Campbell, Scottish Power Energy Networks

Luke Fraser, Orkney Islands Council

Dr Martin Smith, School of Chemistry, University of St Andrews / Common Weal Energy Working Group

Peter O'Donnell, Hebridean Housing Partnership

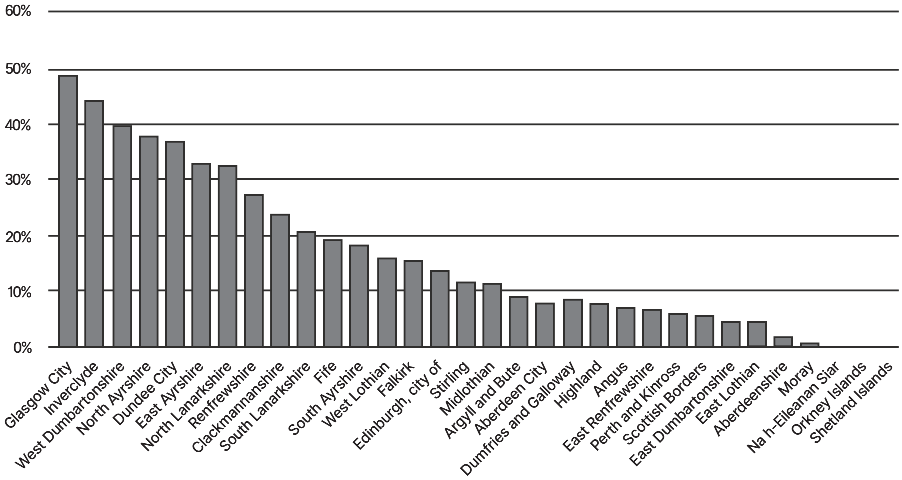
Peter Mildenstein, Pinnacle Power

Richard Hanson-Graville, Thermal Integration Ltd

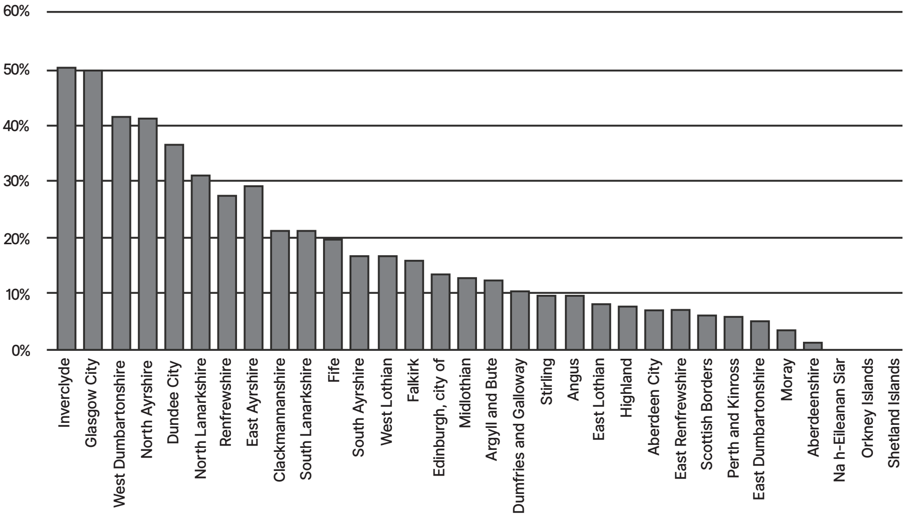
Scott Restrick and Helen Melone, Energy Action Scotland / the Energy Poverty Research initiative

Prof Emeritus Sue Roaf, Heriot-Watt University, Edinburgh

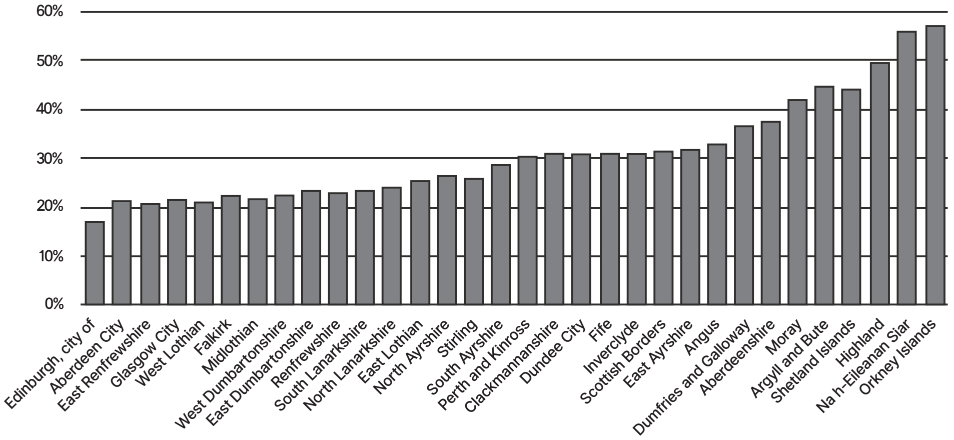
APPENDIX: REGIONAL STATISTICS



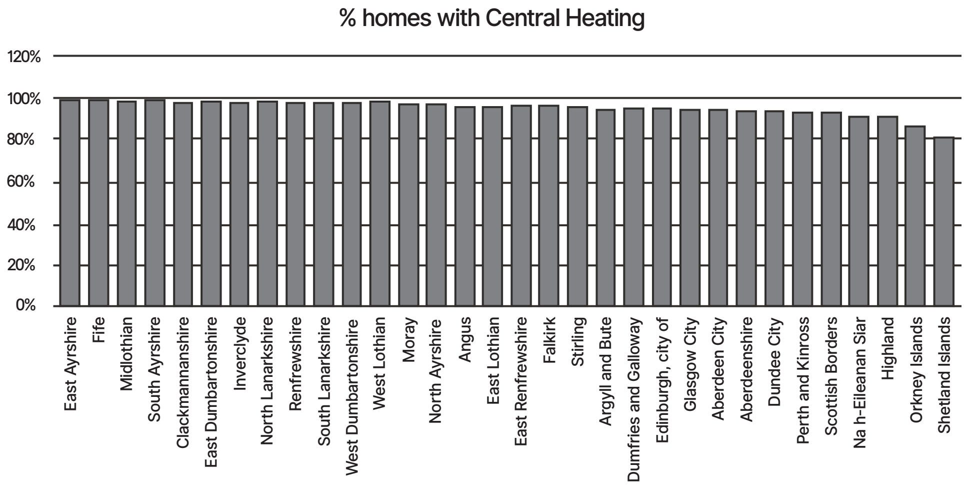
% SIMD overall rank in lowest quintile



% SIMD income domain in lowest quintile



% homes in fuel poverty



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