A Practical Approach:

Analysis of Off-Grid Heat Decarbonisation Pathways

Technical paper

Liquid Gas UK

Introduction

Complete decarbonisation of energy use in buildings within a single generation. That is the target if the UK is to meet its net-zero emission objective. According to the Committee on Climate Change's (CCC) recent 'Net Zero' report, decarbonising heat will be one of the most challenging areas to address by 2050[1].

Heating and hot water is the largest source of energy consumption within UK homes and a radical change to the way in which over 25 million homes are heated currently seems inevitable. The UK government has already committed to tightening new build standards with no new fossil fuel connections after 2025 and there is a likely need for a significant retrofit programme to address the 90% of the current housing stock that will still be standing in 2050[2].

30 years is not a long time to deliver such a substantial transition. The average boiler is expected to last 15 years[3] so a new boiler installed today would reasonably be expected to still be operating in 2035. For many homes there may only be one further opportunity to intervene in choice of heating appliance between now and 2050.

Policy intervention will be needed in the 2020s to set the market-incentives and basis for heat decarbonisation. The UK, Scottish and Welsh Governments are currently developing policies which set a pathway to decarbonisation.

Addressing homes located off the gas grid is the critical inflection point in the decarbonisation of heat across the UK. Government has committed to start here and it is in rural homes where alternative heat solutions will be first deployed at scale.

This paper demonstrates the important role that a mixture of technologies and fuel combinations - including biopropane - should play in lowering emissions from off-gas grid heating to levels aligned with net-zero emissions by 2050. Liquid Gas UK supports a practical approach to heat decarbonisation which seeks to achieve climate change objectives at the least cost and disruption for the consumer.

Our analysis of rural off-gas grid homes based on the real physical features of these homes (type of construction, age, location etc.), shows that there is a substantive case for the decarbonisation of these properties using a mixed technology approach that includes low carbon fuels. This approach supports greater consumer choice and is shown to be more cost-effective than a single technology pathway.

Key messages

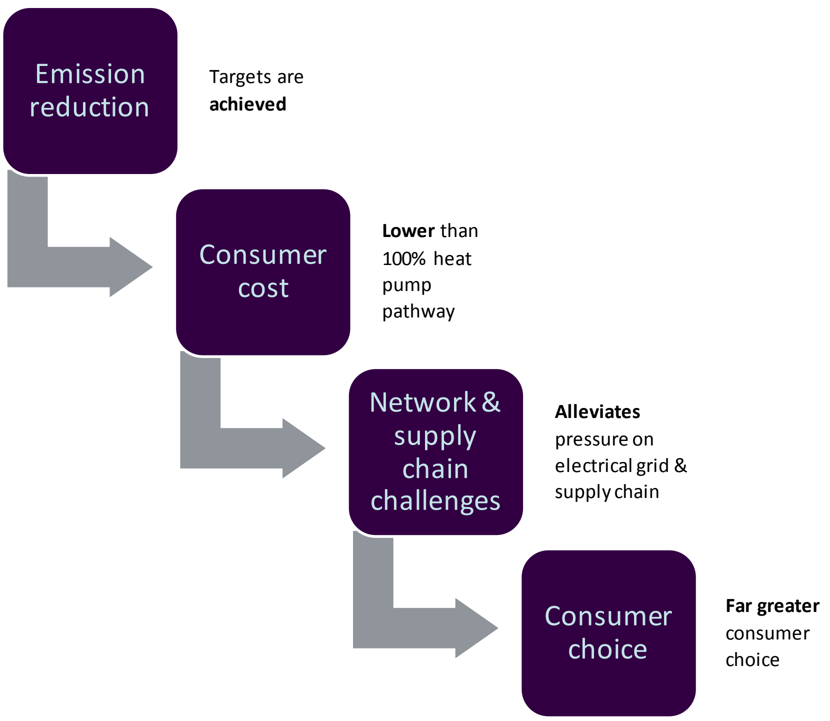
1. High carbon fossil fuel heating will need to be phased out over the coming years. The Government has recognised this in the Clean Growth Strategy, but without policy intervention it is unlikely that emissions will fall by enough to align with a net-zero scenario by 2050.

2. A mixed technology switch allows a flexible approach to meeting decarbonisation targets reflecting the needs of the consumer. There is no silver bullet for the decarbonisation of off-grid heat. Instead, a mix of low carbon heating alternatives will mean that consumers can tailor their choice of system according to their preferences and property types, allowing better choice versus a single technology approach.

3. This is especially important as replacement rates will need to increase compared to historical levels for the targets to be met, by allowing as much choice as possible the likelihood of this increases.

4. The UK Government needs to develop policy incentives that support a mix of low carbon solutions, including biopropane (bioLPG). This analysis shows a role for biopropane in standalone boilers and as part of hybrid systems with an electric heat pump.

Mixed technology approach



Headline Analysis

Background

This paper was commissioned by Liquid Gas UK in order to contribute to the debate at a critical time in the decarbonisation of rural heating. The work was overseen by Liquid Gas UK with analytical support from Ecuity Consulting LLP. All views expressed in this note are those of Liquid Gas UK.

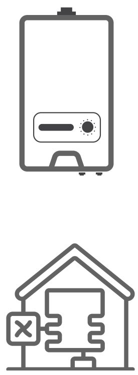
The objective of the report was to set out a practical approach to heat decarbonisation for rural homes across the UK, which seeks to achieve climate change objectives practically and at least cost. This was achieved through the development of several different technology scenarios for off-gas grid buildings.

This paper provides an assessment of the consumer cost of different heat decarbonisation scenarios for off-gas grid buildings, and assesses which of these scenarios is the most cost-effective. This assessment is made based on in-depth modelling of the UK's off-grid building stock, utilising data from the English Housing Survey, as well as technology cost and performance data from sources, such as BEIS and the CCC. See the method below:

48 housing archetypes analysed

Single-family homes: detached, semi-detached, terraced and bungalows

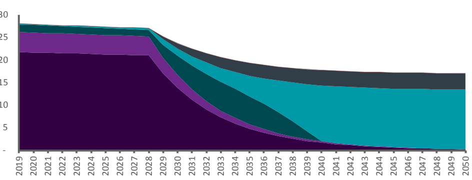
Levelised cost of heating systems calculated: 2018-2050



7 technologies: boilers (oil, coal, LPG, biopropane, biomass) and heat pumps (electric ASHP, hybrid)

Account for capital and fuel bill costs over time

From 2029, house switches to cheapest low-carbon heat option when replacing boiler



Gives fuel consumption and greenhouse gas emission results for the off-gas grid sector scenarios

Results

This paper shows that a mixed technology approach to off-grid heat decarbonisation can deliver significant emission savings aligned with climate change targets, at a lower cost than a pathway that just supports electrical heating. It is clear therefore that a range of technologies including LPG and bioLPG should play a role in this transition. This reflects the need to decarbonise a variety of housing types with technologies that have different characteristics. Government should develop policies that support consumer choice and a range of low-carbon solutions.

To analyse the costs of different heat decarbonisation pathways, a number of scenarios have been developed the first of which, Business as Usual, reflects the status quo with no further policy interventions up to 2050. Here, oil and coal consumers don't switch to lower emission heating technologies.

To reflect the Government's stated intention to phase out the new installation of high-carbon fossil fuel heating in off-grid homes in the 2020s[4], we have developed 2 scenarios that include a 2029 ban on the installation of new fossil fuel heating systems. In practice this means that after this date, when fossil fuel heating systems reach their end-of-life they are replaced with a low-carbon heating system or the fuel is switched to a 'drop-in' renewable alternative such as biopropane.

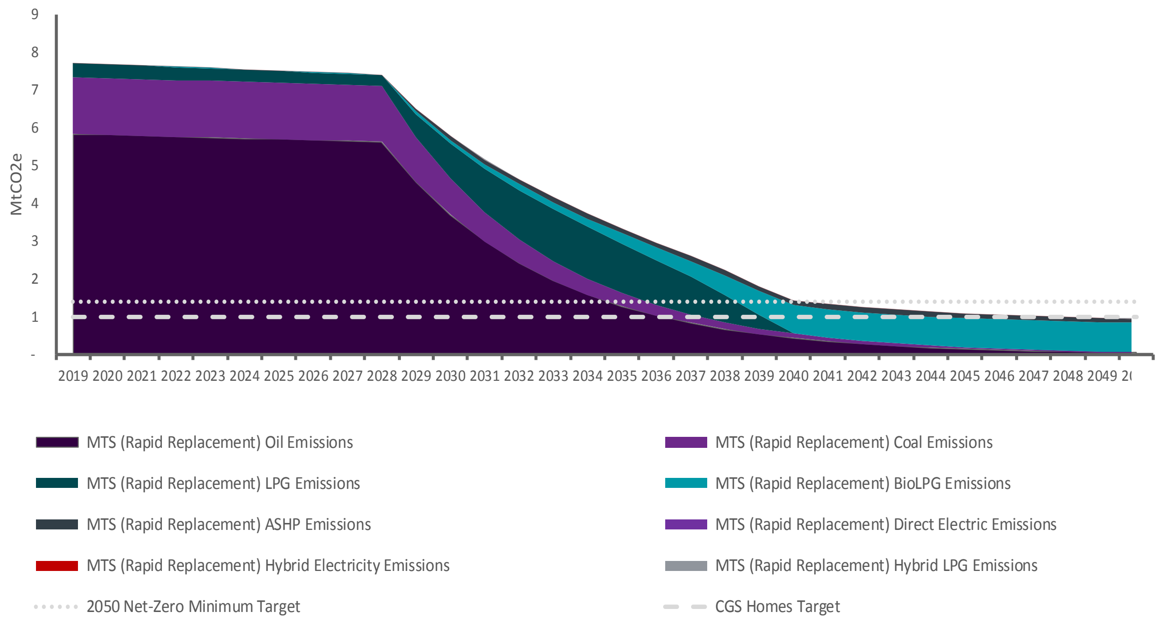
To consider the different technology route options we developed two pathways, one Electrification pathway where electric heat pumps are the only replacement technology and a second where a Mixed Technology Switch to a variety of low-carbon and renewable heating options – including, LPG/biopropane, biomass, electric heat pumps and hybrid heat pumps – is considered.

The rate of change of heating systems becomes important as the UK aims to switch fuels and transition to lower emission heating technologies in each home. The typical rate of boiler replacement is therefore considered (scenarios 2a and 2b), as is an expediated 'rapid' rate of switching (3a and 3b).

The table below provides a summary of the different scenarios and the associated emissions. It is found that both Mixed Technology Switch (scenario 3a) and Electrification with Rapid Replacement (3b) can achieve emission reductions that are aligned with net zero targets, with 90% and 95% reductions achieved by 2050.

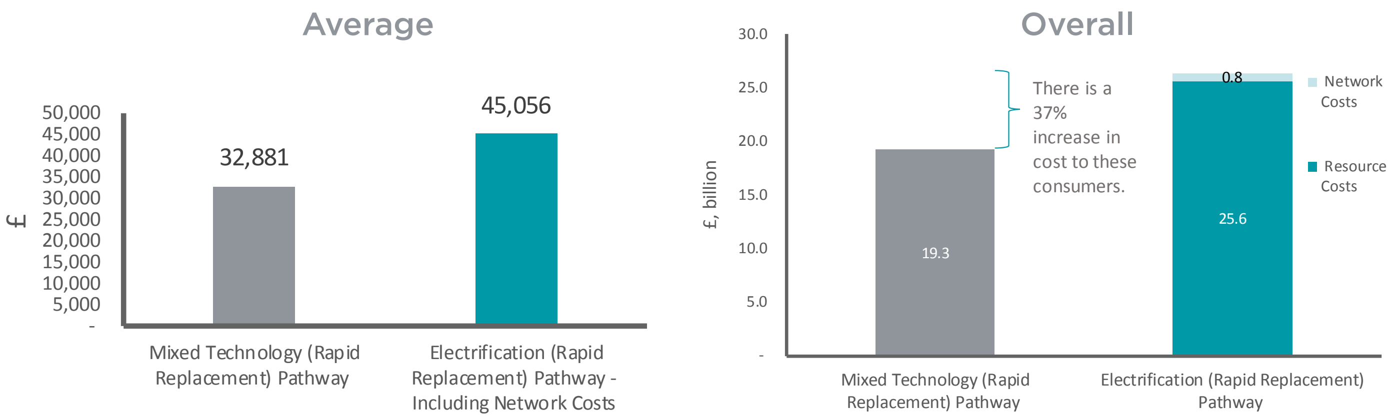
	2050 Emissions ($MtCO_2e$)	2019-2050 Emission Reduction	Are the emission reduction targets met?
1. Business as Usual	6.62	15%	No
2a. Electrification	1.91	75%	No
2b. Mixed Technology Switch	2.36	70%	No
3a. Electrification (Rapid Replacement)	0.41	95%	Yes
3b. Mixed Technology Switch (Rapid Replacement)	0.96	90%	Yes

Mixed Technology Switch (Rapid Replacement) Emissions



Crucially the Mixed Technology Switch pathway delivers decarbonisation at a lower cost to consumers – whilst protecting choice. In particular older homes which are larger than average, less energy efficient and make up just over half of the housing stock analysed face a significant cost increase of 37% under the blanket electrification scenario (see graphic below).

Costs for Older, Large Off-Grid Homes



A mixed technology approach offers flexibility to consumers that could therefore be valuable throughout the decarbonisation process, especially as it has been shown through Scenarios 3a and 3b that an increased rate of replacement is likely needed for the 2050 target levels to be met, and so should be considered as the best route forward for the decarbonisation of the off-gas grid sector.

Summary of results

The mixed technology approach achieves the emission reduction target set out in this analysis and has 3 main advantages over the electrification pathway:

1. Cost – the mixed technology approach has a lower aggregate consumer cost than the electrification pathway, as technologies are installed where it is most cost-effective to do so. Consumers living in older less energy-efficient homes – such as heritage buildings - would face energy cost increases if electric heating through heat pumps was the only option. The analysis also includes an estimate of the additional network costs that would be associated with a 100% electrification approach. These would include a mix of upgrades to the distribution network, integration of flexibility resources (e.g. batteries), and the building of additional renewable power generation to meet peak heat demands. With these costs included, consumers would face costs that are 37% higher through the electrification pathway than the mixed technology approach.

   As other studies have already concluded,[5] a mixed technology or hybrid approach, can substantially lower the network and system costs associated with heat decarbonisation.

2. Alleviates pressure on electrical grid and supply chain – the accelerated uptake of electrical heat pumps is constrained by network engineering challenges, and a supply-chain which will need to scale over time. A vastly increased number of trained heat pump installers will be needed, and likely further investment in the electricity distribution network. Both the necessary training and re-skilling of workers, and network upgrades will take time.

   A mixed technology approach allows progress to be made faster by utilising existing expertise and supply chains. For instance, the existing LPG supply chain and installer-base are already able to facilitate switching from heating oil, offering an immediate lower carbon solution with LPG and long-term decarbonisation solution with biopropane. Failure to act will mean that heating system replacement opportunities are missed in the near and medium term.

3. Consumer choice – consumers have a range of preferences and live in a diverse set of properties. Policy should recognise this diversity by supporting a range of low-carbon heating options and ensure that consumers will have choice between these. This lowers the political risk associated with favouring a small number of technologies, and targets outcome (emission reduction) rather than favouring certain means of achieving this.

Policy Landscape: Heat Decarbonisation for Off-Grid Homes

The UK must achieve decarbonisation by mid-century to meet its recently legislated net-zero objective and align with the Paris Agreement. In effect, this means that economy-wide emissions should be eliminated by 2050.

This is a significant challenge, but also an industrial opportunity for UK businesses to deliver new energy products, and improved services to consumers. UK emissions have fallen by 42% since 1990[6] whilst GDP has grown by 72%,[7] demonstrating that market-led decarbonisation can deliver both growth and sustainability.

Energy supply and the power sector has led the way in delivering emission reductions, accounting for nearly 50% of the UK's progress since 1990. Here, the shift from coal to gas-powered power stations and renewables has been particularly successful in lowering emissions.

As this power-sector transition runs its course and opportunities are depleted, Government will look to other sectors of the economy to deliver further emission reductions.

Emissions from both the transport and residential sector have remained relatively stable over recent years (see figure 1 below), and slow current progress shows that decarbonising these sectors by 2050 will be particularly challenging.

Specifically, The Department for Business, Energy and Industrial Strategy (BEIS) consider that emissions from residential buildings may need to fall from 74 $MtCO_2$ a year to 6 $MtCO_2e$ by 2050[1 & 4]. This is a substantial reduction in a relatively short timeframe.

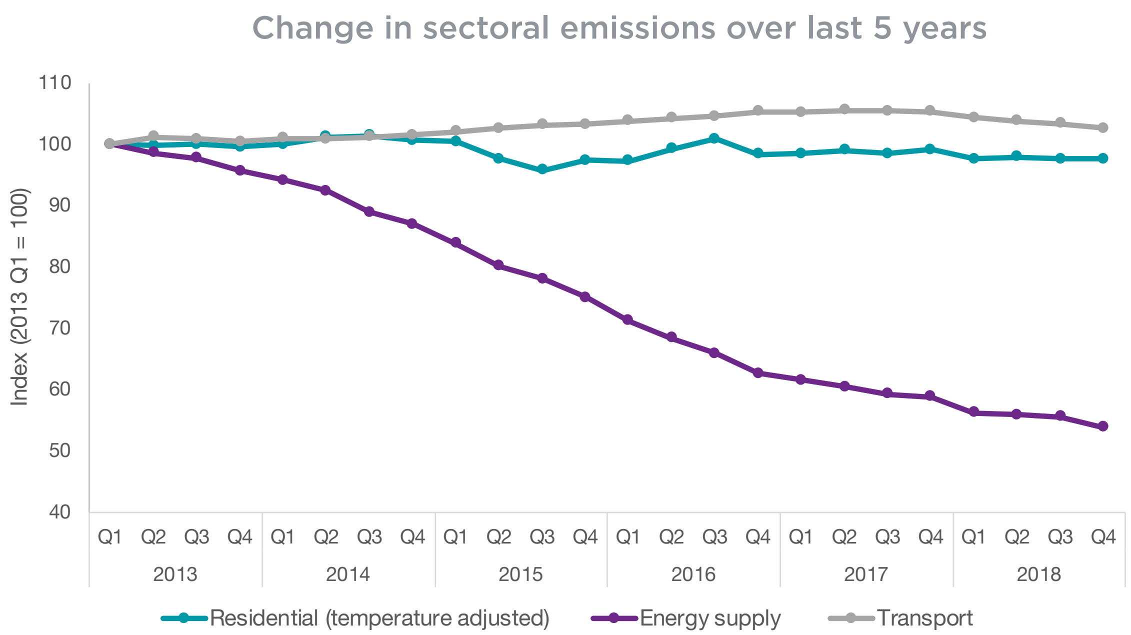


Figure 1 - change in UK sectoral emissions between 2013 and 2018 (BEIS, 2019) (source: DECC)

UK Government

The UK's Clean Growth Strategy recognised the central importance of decarbonising heat, and the specific opportunity to start transitioning oil or coal heated homes onto lower carbon solutions. Emissions from homes that are situated off the gas-grid have been highlighted by BEIS as an immediate area of decarbonisation.

In preparation for the expected closure of the domestic Renewable Heat Incentive subsidy scheme in 2021, BEIS are expected to consult further on the policy framework needed to incentivise a switch from high emission fuels in the off-gas grid sector. However, incentivisation cannot last forever. Therefore, the most cost-effective approach for Government and homeowners is to have a competitive market place where costs can be driven down.

The analysis included in this report takes account of consumer behaviour, the off-grid housing stock, and technology options available, and provides insight into the timing and decarbonisation impact of a policy intervention. The analysis shows that transitioning oil-heated homes in the off-gas grid sector away from high-emission fossil fuels will take time, and that a mixture of technologies should be supported as low carbon alternatives in rural areas – including boilers fuelled by biopropane, electric heat pumps and hybrid heat pumps.

Welsh Government

The Welsh Government released Prosperity for all: A low carbon Wales vision document in 2019 which sets out the country's policies and plans in respect to action on climate change. The plan reaffirms Wales' 2030 target to reduce emissions from buildings by 40% (from 1990 levels).

Several policy approaches have been developed to support emission reductions from buildings. including new-build research and development funding, energy efficiency grant schemes and the tightening of building standards.

Of note is the Welsh Government's approach to energy planning, which involves mapping the most appropriate sources of low emission heat. This process recognises the complexity of heat decarbonisation, and the variety of potential technology options which should be assessed based on specific local circumstances.

Scottish Government

The Scottish Government is also actively developing policy to encourage heat decarbonisation to meet the country's 2032 target of delivering 32% of domestic heat from renewable sources. In its 2018 route map ('Energy Efficient Scotland'), the Scottish Government mapped out a 20-year programme to deliver warmer, greener and more energy efficient homes by 2040.

Emphasis has been placed on the importance of local delivery of building retrofits, with local authorities tasked with taking a more active role in the deployment of energy efficiency measures and low-emission heating systems. This approach recognises the regional specificities of the building stock and household conditions (such as incidence of fuel poverty) across the country, the area-expertise of local authorities, and sets the ground for the deployment of a mixture of low-carbon technologies based on local circumstances.

Challenges with decarbonising the off-grid housing stock

The analysis developed in this report considers the various physical characteristics of the off-gas grid building stock and analyses the effectiveness of a number of low-emission heating technologies. Decarbonising heat will require a variety of approaches to address a diversity of building types, several ownership and occupancy characteristics, different technologies and fuels, and an appreciation of the personal circumstances of householders.

The off-grid housing stock is generally split between newly built apartments – often located in urban areas – for which modest heating demands are met by electric panel/storage heaters with no need to be connected to the gas grid, and homes that historically have sat outside of the reach of the grid. These homes are typically located in rural areas and are often older, less energy efficient and have a higher heat demand.

It's these rural off-grid properties that are most likely to consume heating oil or coal, and where the greatest emission reductions can be achieved.

This paper will focus on rural, off-grid single-family homes which currently use fossil fuels (heating oil, coal or LPG) to provide heating. This covers an estimated 1.5 million properties. These homes will need to transition away from fossil fuel heating to low-carbon alternatives over the next 20-30 years. This paper explores the options available.

It is these properties that typically have a large heat demand and consume high-emission fossil fuels for heating. This is the section of the off-gas grid building stock which will be analysed in detail in this report.

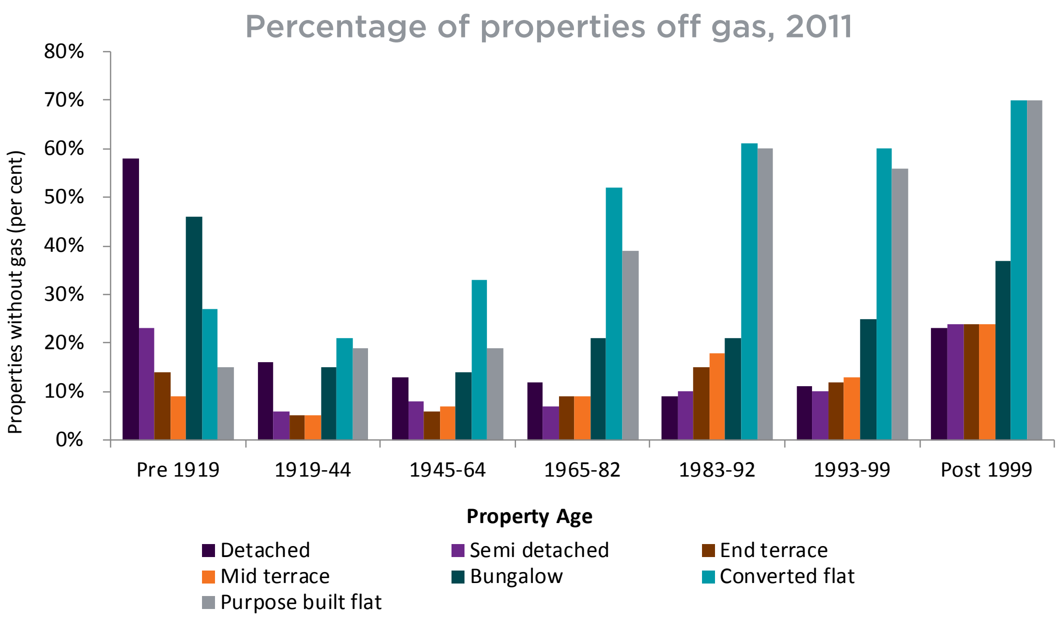


Figure 2 - percentage of the estimated number of properties located off the gas-grid, by property type and age

It is therefore important to consider the changes that these properties will need to go through to decarbonise by 2050 and be compliant with net-zero. A transition from the consumption of carbon-intensive fuels such as heating oil, to lower emission technologies and fuels will be needed.

In particular, oil-heating is targeted as the primary off-gas grid fossil fuel. The emission reduction potential of a switch away from kerosene to a low-emission alternative such as biopropane, or electric heat pumps, is significant, and whereas biopropane has already seen consumption in the heating market, there has been no such consumption of lower emission bio-oil.

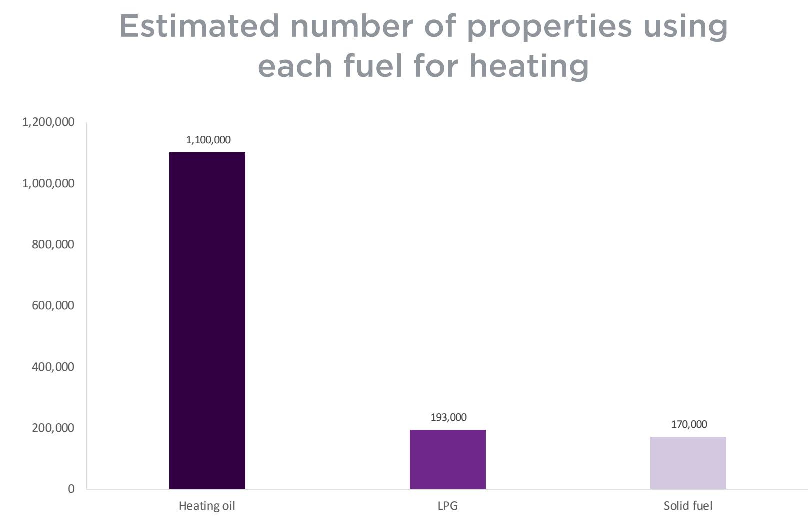


Figure 3 - estimated number of LPG, heating oil and solid fuel properties in Great Britain (source: BEIS & NNFCC)

There are substantial emission savings that can be achieved by switching away from heating oil and coal to a low-carbon alternative. For a typical detached off-grid home, and one of the building-archetypes developed for the analysis, emission reductions of between 71%-86% can be delivered by switching to biopropane or heat pumps (hybrid and standalone). Of these low-carbon alternatives, on average, biopropane can also cost the consumer around 37% less up to 2050.

Homes heated by LPG will also need to be addressed, and the development of biopropane – as a direct replacement drop-in for conventional LPG – provides a pathway to decarbonising heat consumption in these properties. The analysis included in this report considers an increasing role for biopropane over coming years as a section of consumers switch from LPG, oil and coal to this fuel.

Whilst the potential for substantial emission reductions is clear, there are a number of specific challenges to highlight.

(i) Rural, off-gas grid properties are often hard to treat

Many rural, off-gas grid properties have low levels of fabric efficiency and air tightness and, combined with the use of traditional materials, are difficult to treat. Emissions reductions can be achieved by a combination of reducing the property's energy demand and transitioning to lower emission energy sources and technologies. Both demand-side and supply-side measures will be needed.

Housing survey data suggests that a large proportion of rural off-grid homes are relatively old, for example over 25% of oil-heated properties featured in the English Housing Survey data used in this study were built before 1918. Older properties are typically less energy-efficient, which can make installing some energy efficiency measures and the building-retrofit needed for certain electrical heating technologies more challenging and expensive. In addition, some of these properties have a heritage value and character which may require bespoke low-emission solutions[1].

For some buildings of heritage value for instance, the installation of external-wall insulation would be damaging to the building's appearance. This challenge has been recognised by the Committee on Climate Change in their 2019 net-zero report[1]. Oil-heated properties are more likely to have solid-walls, which are more challenging and expensive to insulate to a good standard than cavity walls and are therefore a widespread characteristic in the types of homes considered in this report. BEIS estimate that 91% of the 8.5 million solid wall properties lack external or internal wall insulation. The proportion of uninsulated solid wall properties is clearly high and has remained so for the last 5 years. This demonstrated both a lack of awareness and interest in solid wall insulation among householders.

Indeed, in 2018, 14% of respondents to a BEIS survey hadn't heard of solid wall insulation. A further 20% hadn't considered installing the technology, and 16% actively didn't want to[8]. The high price of installation (£5,000 - £11,000 assumed by BEIS[9]), potential disruption and alteration to the appearance of rural buildings means that for many off-grid householders, the installation of solid wall insulation is unattractive.

It is crucial, therefore, that net-zero compliant heat decarbonisation options are developed for the full range of building types – including hard-to-treat rural properties.

(ii) Home retrofits will cost time and money

Decarbonisation of heat will require numerous interventions across the UK, as householders will be tasked with changing the way they heat their homes through the installation of new heating systems and physical changes to their home. As it is possible that over 90% of existing homes will still be standing in 2050[2], it is important to consider the complexity, costs and inconvenience of retrofit measures in existing homes. Disruption, hassle and costs should be minimised to ensure consumer buy-in, support and action.

Cost is a particular consideration for many households in rural areas, where for example, the average fuel poverty gap is £600 for rural households in England, more than double the figure for urban areas. Current figures suggest that across all Great British households, over 2.55 million households are in fuel poverty in England (by the 'low income high cost' metric), with a further 650,000 households in Scotland[10] and 291,000 households in Wales.

LPG and biopropane offers decarbonisation with minimal disruption, through a type of heating system that consumers will already be familiar with and with relatively minor changes needed in the home for the installation.

It isn't clear how the burden of these financing costs will be shared between consumers, industry and Government, but it is likely that householders will face the majority of these retrofit costs.

Heating system changes can typically cost between £1,000 - £15,000, with investment in low-carbon electric heating technologies, such as heat pumps, typically costing significantly more upfront than traditional technologies. For many households this level of additional capital investment is seen as unattractive or unattainable, and it is likely that Government policy will be needed to support fuel poor households in rural areas where the incidence and depth of fuel poverty is most severe.

Current uptake of lower emission heating systems and energy efficiency measures is modest amongst able-to-pay households in the UK. As an indication, BEIS estimate that since 2013, over 99% of cavity wall and loft insulation measures have been delivered through the Energy Company Obligation (ECO)[11] - a Government scheme – leaving virtually no delivery from the able-to-pay sector.

While part of the issue is a lack of awareness, it's clear that cost and familiarity of low-emission electrified solutions, such as heat pumps or hybrids, remain influential barriers to heat decarbonisation. Of the respondents to a BEIS survey question asking why they'd be unlikely to install a renewable heating system, 30% responded that they wouldn't because the cost would be too high, with a further 10% noting the hassle of installing something new.

In addition, the majority of consumers look to change their heating system when it is close to breaking down – with close to 70% of respondents to a BEIS survey noting that they only replace their heating system when the current one breaks down or deteriorates. In this 'distress purchase' scenario, the level of disruption and the time taken to replace the existing system will likely influence which heating system the consumer. In this circumstance, existing heating infrastructure – such as a heating oil tank – can act to lock-in consumers into high carbon fossil fuels.

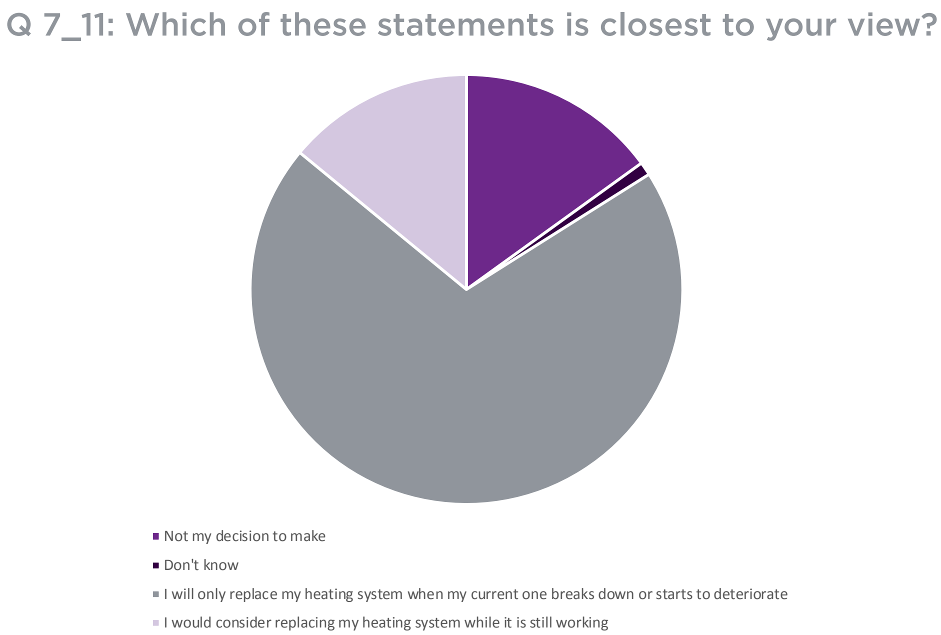


Figure 4 - principal reason for replacing heating system - householder response to BEIS survey

Additionally, the time taken to retrofit a property and install a new heating system can be off-putting and disruptive. Whilst some lower emission heating systems can be installed relatively easily as a replacement in typical off-grid properties (e.g. LPG/biopropane), other technologies require significant work to be installed effectively – such as electric heat pumps which often require the replacement of radiators and the laying of ground-loop collectors amongst other ancillary measures.

Low capital-cost and disruption technology options are a priority for consumers in their decision making and a boost to the acceptability of efforts to decarbonise off-gas grid heat, which will be fundamental to seeing the sufficient decarbonisation of off-grid heating.

There are numerous different pathways to achieve heat decarbonisation, and a variety of technologies that could play a long-term role in the energy mix. Solutions need to simultaneously deliver on sustainability, affordability and security, and crucially need to be supported by householders. With each technology having a variety of characteristics, cost and constraints, there is no obvious optimal technology approach to heat decarbonisation.

An analytical approach is therefore needed, to break down cost-effective emission reduction potential and targets, and an understanding of the building stock and consumer realities which will impact the feasibility of each technology.

This report, and the analysis underpinning it, will suggest that the most cost-effective solution for UK consumers is a mixed technology approach to off-grid heat decarbonisation – offering consumers a range of technology solutions to best fit their preferences, building types and personal circumstances at the same time as being consistent with a net-zero pathway.

As part of this mix of technologies, LPG and biopropane has a clear role to play, offering a substantial share of those houses currently heating using oil and coal the most cost-effective route to net zero.

Technology options for off-grid heating

Several technology and fuel combinations have been considered as part of the analysis for this study. These are by no means exhaustive of the potential options but can be considered as representative of the principal technologies available off the gas-grid. Each have their own advantages and disadvantages, the highlights of which are listed in Table 1.

TECHNOLOGY	ADVANTAGES	DISADVANTAGES
LPG Boilers using Biopropane	• High temperature heat provided • Consumer familiarity • ‘Drop-in’ fuel with biopropane • Low carbon • Low NOx and SOx emissions • Very small $PM_{2.5}$ emissions	• Increased biopropane production needs to be supported
Air Source Heat Pumps	• High efficiency levels • Low carbon emissions • No NOx or PM2.5 emissions	• High upfront costs, including radiators and insulation upgrades • Unfamiliar to consumers • Large space requirement
Biomass Boilers	• High temperature heat provided	• High upfront costs • High NOx and $PM_{2.5}$ emissions • Large space requirement
Direct Electric Panels	• Low upfront costs • Low space requirement • Low carbon	• High running costs
Hybrid Heat Pumps	• Offers both high and low temperature heat • High levels of efficiency • Low carbon emissions	• High upfront costs • Limited consumer awareness and deployment to date • Large space requirement

LPG Boilers powered by Biopropane

LPG boilers are a technology which consumers are already familiar with and widely use. They provide high temperature heat making them especially suitable in harder to treat homes and commercial and industrial processes. LPG boilers have relatively low upfront costs. Homes would require no extra upgrades for an LPG boiler to be installed and LPG offers immediate carbon savings, compared to the use of oil and coal.

For the low carbon emissions to be realised from biopropane, there must be a development of supply and a matching recognition in policy that acknowledges the emission reductions that could be achieved here. Liquid Gas UK are conducting an independent study into the feedstocks needed for the development of biopropane.

LPG/biopropane systems work with a combination boiler, removing the need for any storage system, there is no need for noisy units outside of homes like heat pumps and they offer a complementary renewable fuel source for homes using solar and wind energy when the wind isn't blowing and the sun isn't shining[12]. LPG boilers also have very low levels of NOx emissions and minimal $PM_{2.5}$ emissions, providing a considerable air quality advantage compared to biomass heating systems[13].

Biopropane

Biopropane is a versatile, 'drop-in' replacement low-carbon solution that can be used in existing LPG boilers. It's a direct replacement for conventional LPG and can be used by consumers in their existing heating appliances, stored in existing bulk tanks and cylinders, and transported using today's infrastructure and skilled workforce.

It has the same chemical identity as conventional LPG which makes it a flexible energy source that can be cost-effectively stored, transported and consumed at the convenience of off-grid consumers. This is an extremely useful feature given the intermittency of heating demand; reliably meeting the variability of heat demand with decarbonised energy supply has been highlighted as a potential issue with a pure electrification pathway.

Biopropane can play a pivotal role in offering a mixed technology solution to the decarbonisation of heat. The electrification of heat will place increased strain on the electricity grid and particularly so in rural areas where the grid is likely to be less developed and able to respond to flexible peak heat demands. Here biopropane can help to avoid the pressures on the grid in rural areas.

Indeed, the CCC[14] recognise the role for biopropane as part of heating in off-gas grid homes in 2050 under a 'net-zero' scenario. The low carbon intensity of biopropane means that substantial emission reductions can be delivered on top of the advantages to the consumer already discussed. Biopropane's emission intensity has the potential to be 88% lower than heating oil, depending on the feedstock and method of production.[15]

The further development of biopropane supply for heating is key to a mixed technology solution for decarbonising heat and any premium which consumers may have to pay over conventional LPG could come down with this scale, as considered under the analysis. It is a broad aim for the industry that by 2040 all LPG consumption is through biopropane, this has been reflected in all of our analytical scenarios. Policy should therefore support the development of biopropane production pathways, many of which can be supplied by sustainable domestic feedstocks.

Electric Heat Pumps

Heat pumps work using the reverse of the process used by refrigerators, taking energy from surroundings and forcing it to a higher temperature which can be used to heat the inside of a building[16]. By making use of the surrounding energy, this process has high efficiency levels, meaning that a lower amount of electricity is needed to provide the same amount of heat as compared to traditional direct electric heating.

Electric heat pumps are often viewed as a core part of the solution for heat decarbonisation, because they are efficient and as the power grid decarbonises, they will produce fewer emissions[1]. However, as a technology they are relatively unfamiliar to consumers in terms of both the extra space needed and the low temperature of heat that is typically provided.

In addition, the upfront cost of heat pumps is relatively high, and installation can require the upgrading of heat emitters and additional building-insulation for the system to work effectively. The added demand placed on the electricity grid by heat pumps will also require infrastructure upgrades, which in rural locations with a lack of property density and opportunity for economies of scale can have a high relative cost per property.

There are several types of heat pumps on the market, however, for the purpose of this analysis, electric air source heat pumps have been considered as the dominant technology deployed under the domestic RHI[17].

Biomass

The analysis also considers biomass boilers in the form of a pellet-based system, which tend to be larger than more traditional oil or gas boilers. The system works by controlling automatically for the quantity of pellets being used as well as the air flow, improving the efficiency of the heating method[18]. These systems have relatively high upfront costs, but they can deliver lower operating costs, making them often suitable for larger, commercial installations where the initial investment can be spread over a larger heating demand. Although biomass pellet boilers are relatively low carbon, research has found air quality issues from biomass heating systems[19]. Particularly there are incredibly high NOx and $PM_{2.5}$ emissions associated with the burning of wood.

Electric Panel Heaters

Direct electric panel heaters are a well-established heating option, which provides heat through convection to directly warm the air in a room. This means that they can be a fast and effective source of heat[20]. They are however less efficient than heat pumps, meaning that, although the upfront cost is lower, the running costs are typically higher.

For the off-grid single family homes analysed in this report, the relatively high heating demand of the properties analysed can result in fuel bills that are expensive when heated by electrical panel heaters. They are typically most suitable for installations where space constraints are an issue and the heat demand is low, such as apartment blocks. As with any electric solution, they can be viewed as a low emission option as the grid decarbonises due to increasing renewable generation of electricity.

Hybrid Heat Pumps

Hybrid heat pumps typically combine an electric heat pump with an additional backup boiler. This combination can be developed with varying levels of sophistication of communication between the two systems and although sales are relatively low at present, the CCC believes they will have a role to play in achieving net-zero emissions by 2050[1]. Therefore, they have been considered a technology worth modelling as part of this study. We have considered a bivalent system, including an air source heat pump operating in conjunction with an LPG/biopropane boiler, again this use of biopropane aligns with the CCC's technology projection for a net-zero pathway[1].

The boiler can operate during times of the year (peak heat periods in winter for instance) when the heat pump would operate less efficiently, thereby improving the overall efficiency of the system. This means that fuel bills can be relatively low, but a higher upfront cost is often required, particularly where the heating system in situ also needs to be replaced, as is the case in this analysis. They can be viewed as a low carbon option, with the decarbonising electricity supply used by the heat pump being combined with a low carbon fuel, such as biopropane, for the boiler. However, unless hydraulically separated, the boiler is still limited by the maximum flow temperature of the heat pump, which means that disruptive upgrades to heat emitters would still be required.

Oil Boilers Fuelled with Biokerosene

Another potential biofuel that was considered for the analysis was biokerosene, which has been proposed as an alternative to conventional oil heating off the gas grid. The use of biokerosene technology is however speculative, as there is not yet any real market use of the fuel for residential heating, unlike biopropane. This means that there are knowledge gaps surrounding the fuel properties of blends and their suitability.

It has been shown experimentally that a blend of 30% biokerosene can be used with conventional fuel oil (making the remaining 70%) in existing oil boilers. This fuel, termed B30K, only lowers GHG emissions marginally compared to pure kerosene boilers (~28% reduction) but could be adopted quickly.

However, for blends above B30K a step-change in boiler design and fuel handling is needed. This is because boilers, tanks and pipework will need to be changed due to issues with material compatibility from the new characteristics of higher biokerosene blends.

The knowledge gaps surrounding the different properties from the various blends of biokerosene may create further issues. For example, the feedstocks for biokerosene may have higher cold filter plugging points, (an estimate for the lowest temperature that a fuel will give trouble free flow in certain fuel systems) making them potentially problematic in cold weather.

In warmer weather, biokerosene will oxidise and go rancid if stored for too long. This can mean that oil tanks would have to reduce in size to facilitate more frequent deliveries to overcome this issue, creating increased costs and emissions as a result[21].

This will create a need for numerous supply chain changes, with a need for companies to change their tankers, for example, between each blend. Due to the varying characteristics of the different blends, there is also no 'fall back' option in the event of insufficient supply, which could be problematic for security of supply during transitional periods.

The technical development of purely biokerosene boilers is also still ongoing and any major announcements in the short term seem unlikely[22]. Most immediately, if biokerosene was able to be commercially produced it will likely service other harder to decarbonise sectors such as aviation where few low-carbon alternatives exist.

Case study 1: off-grid home built between 1945-1964

The following chart illustrates the choice faced by a consumer in 2019 who lives in a single-family, detached home built between 1945-64. Since being built the home has had some significant upgrades in terms of cavity wall and loft insulation, double glazing for the windows and new doors being installed. It shows that an LPG boiler fuelled with biopropane offers the lowest levelised cost option to the consumer.

Old oil boiler is being changed						
What are the options?	Stay with oil getting a new more efficient oil boiler	Switch to an LPG boiler with biopropane	Switch to a heat pump	Switch to a biomass boiler	Switch to a hybrid system	Switch to direct electric panels
Is this a low-carbon option?	No	Yes	Yes	Yes	Yes (with biopropane)	Yes
What is the upfront cost?		£1500	£6570	£8120	£7270	£1400
What is the levelised cost?		£90/MWh	£97/MWh	£132/MWh	£102/MWh	£180/MWh

Methodology

The analysis considers how those homes currently heated by oil, coal and LPG can be decarbonised in line with potential targets for a net-zero pathway. The need for intervention in these homes has been acknowledged by the Government's Clean Growth Strategy (CGS), which states the intention to "phase out the installation of high carbon form of fossil fuel heating in new and existing homes currently off the gas grid during the 2020s"[1].

It is expected that this will begin with new homes before moving onto the existing stock. Thus, under all policy-intervention scenarios developed in this analysis, a ban on the installation of oil and coal systems has been included from 2029 onwards. This means that when consumers look to replace their heating systems from 2029, they must do so with a low-carbon alternative.

A detailed analysis of the English Housing Survey[23] was used to develop 48 different housing archetypes. The focus of the analysis is single-family homes (SFHs) (as opposed to apartments) as these properties are the dominant consumers of oil, coal and LPG heating. This housing-stock information was combined with data from the Intelligent Energy Europe Programme[24] to calculate the heating requirement for each archetype, taking into consideration the varying levels of energy efficiency improvements that have been made since construction. This requirement was then used to inform each heating technology's sizing and running efficiency, as well as data on upfront costs and derived fuel bills, to produce a levelised cost (£/MWh) for each property type and technology option for every year up to 2050.

When choosing a replacement system for oil and coal, it was assumed that consumers would opt for the cheapest levelised cost option.

This levelised cost analysis included modelling of heat pump performance based on technical data and typical UK climatic conditions[25], due to the variation of heat pump efficiency and sizing across different housing types, as well as the upgrades needed for the heat emitters of a suitable size. It was also assumed that those properties currently heating using LPG heating systems would continue to do so up to 2050, due to the development of biopropane providing low carbon heating adopted by these consumers.

This report has developed several scenarios to consider the impact of different decarbonisation pathways and associated costs for single-family homes (SFHs) off the gas-grid which are currently heating their properties using oil, coal and LPG. In order to assess the level of decarbonisation that is achieved across the pathways, two reduction targets have been calculated for this section of the housing stock considered:

1. A reduction to 1.4 MtCO_2e by 2050, reflecting the minimum fall in emissions to align with a net-zero target. Under the CCC's 'Further Ambition' net-zero compliant scenario, this is the level of emissions attributed to the whole off-grid sector by 2050. The sub-section of the off-grid housing sector analysed in this report will therefore, we assume, need to reduce emissions to at least this illustrative level to align with the UK's net-zero target.

2. Such targets are in part determined by the strength of emission reduction efforts made in other parts of the economy. As an upper bound and to reflect the potential for a more stringent reductions requirement for this off-grid segment, an 87.5% reduction on 1990 levels by 2050 is also targeted. This is informed by the Clean Growth Strategy's (CGS) targeted emission range for 2050.

With these targets in mind, five illustrative scenarios have been developed to analyse the potential for decarbonisation of the off-grid sector. Figure 2 provides an outline of the scenarios developed.

Off-Grid Decarbonisation Pathways					
What are the options?	Business as Usual	Electricification (100% heat pumps)		Mixed Technology Switch	
What is the replacement rate?	Historical (6.44% p.a.)	Historical (6.44% p.a.)	Rapid (19% p.a.)	Historical (6.44% p.a.)	Rapid (19% p.a.)
Are the emission reduction targets met?	No	No	Yes	No	Yes
Is this the cost-effective option for consumers?			No		Yes - older, larger homes will save 33% on average.

Figure 5 - overview of scenarios considered for off-grid heat decarbonisation

For each of these scenarios, consumption levels (TWh) of the different fuel types is calculated. Carbon emission intensities for each fuel have then been used to calculate the total greenhouse gas emissions ($MtCO_2e$) produced by each scenario.

To allow for future changes across the time period, the model calculates a levelised cost for each year, meaning that the proportions of consumers opting for the different technologies can change yearly. This allows factors to be considered, such as a learning rate for the cost of heat pumps which reduces upfront costs over time, and a falling biopropane price as premium as deployment of both scales.

In each year the proportion of consumers removing their oil and coal heating systems is reflected through a percentage 'replacement rate', historically this has taken place at a rate of 6.44%[26].

[1] Based on a total oil boiler stock of 1,063,743 and 68,500 sales per year.

Results

Scenario 1: Business as Usual (BAU)

Under the BAU scenario the status quo is maintained, with no policy intervention to encourage consumers to switch away from oil and coal, the proportion of homes heated using oil, coal and LPG or biopropane remains constant up to 2050. This is a conservative scenario developed for illustrative purposes, with minimal action taken by consumers.

Across the BAU time period, there are some small energy consumption changes as heating system efficiency improves over time as a result of consumers replacing their heating systems with newer, more efficient products (see Annex). This rate of replacement is based on an historical level of 6.44% per year and means that between 2019 and 2050 consumption falls by 11% from 28 TWh to 25 TWh.

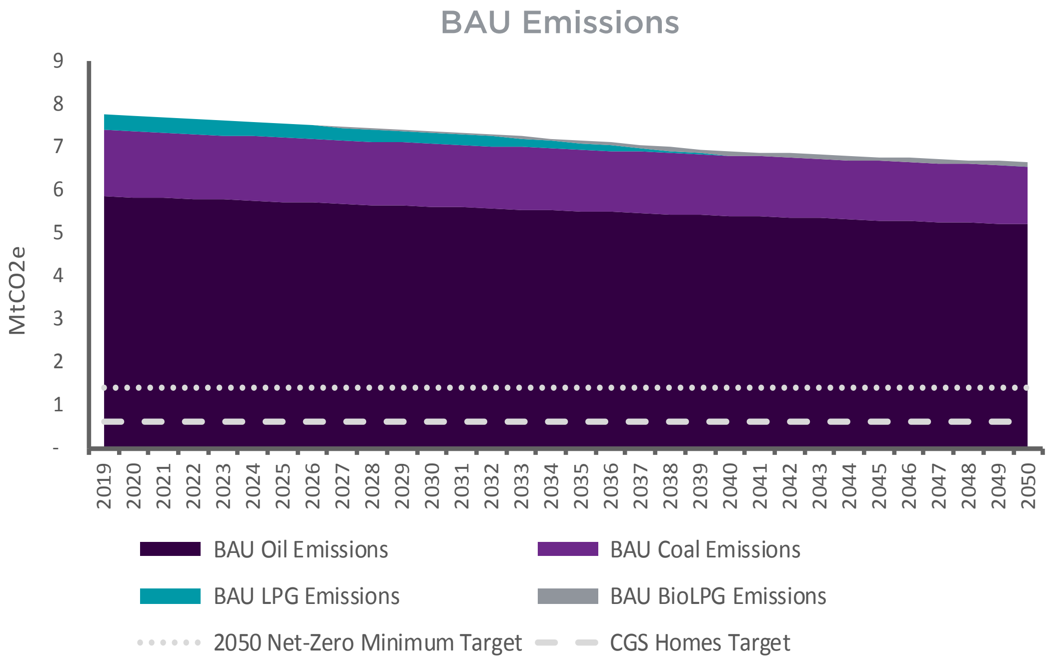


Figure 6 - Business as Usual (BAU) scenario emissions for off-grid homes currently heating using oil, coal and propane ($MtCO_2e$)

As a result of the consumption falling across the period as well as consumers switching from LPG to biopropane, emissions fall by 14% up to 2050 to 6.6 $MtCO_2e$. This level is substantially above the absolute minimum reduction target level of 1.4 $MtCO_2e$ necessary for net-zero emissions by 2050. These results support the case for consumer action and for policy intervention to develop the incentives to encourage and support fuel switching away from high-carbon fossil fuels. Failure to do so will result in missed carbon targets.

Scenario 2a: Electrification Pathway

To reflect commitments made in the Clean Growth Strategy, the policy interventionist scenarios consider that consumers start to switch away from heating oil and coal as a result of a ban on new heating systems. The ban put in place in the remaining scenarios means that from 2029, consumers replacing their oil and coal boiler must do so with a low carbon technology. In practice, this replacement typically happens once a consumer's current heating system has broken down or started to deteriorate[27] - therefore this transition will take time.

The full electrification of heat scenario has been considered as a potential pathway by the CCC[28] for the off-gas grid sector, with a key role played by electric heat pumps. Under this full electrification scenario, all oil and coal heated properties switch to electric heat pumps (ASHP) if and when their existing heating system is replaced. Consumers using LPG are assumed to stay with this technology and shift to biopropane across the time period. This switch happens at the same historical replacement rate, 6.44% per year, as in the BAU scenario.

The switch from oil and coal to electric heat pumps results in a larger reduction in consumption by 2050 (see Figure 14 in the annex), due to the relatively high efficiency performance of heat pumps compared to oil and coal boilers. As a result, final energy consumption falls by 49% across the period to 14.4 TWh.

The reduction in consumption, the switch from LPG to biopropane, and a reduction in the emission intensity of electricity over time mean that emissions are reduced considerably under this scenario compared to the BAU case. Between 2019 and 2050, emissions fall from 7.7 $MtCO_2e$ to 1.9 $MtCO_2e$ - a 75% reduction (see Figure 15 in the annex).

If the UK is to hit its climate change targets, then this pathway is clearly not aligned with the levels of emission abatement required by 2050. The emission reduction is insufficient to meet the level advised for the total off-gas part of the housing stock under a net-zero pathway, let alone any further stretch targets that will likely be needed for the smaller sub-section of the off-grid housing considered. This means that more needs to be done.

Scenario 2b: Mixed Technology Pathway

The mixed technology pathway consequently offers consumers a choice between several heating technologies, namely: air source heat pumps (ASHP), hybrid heat pumps (ASHP paired with an LPG boiler which can be fuelled with biopropane), LPG boilers which can be fuelled with biopropane, direct electric panel heaters and biomass boilers. Not only does this diversify the route to decarbonising heating in these homes, it also increases the choice for consumers.

Under this scenario, at the point of replacing their oil and coal boilers, consumer choice is based on the levelised cost of heating for each of these methods, with consumers choosing the lowest cost option. These cost calculations consider the different variables, such as property characteristics and climate, and the influence that this has on the performance and sizing of the different heating systems.

Consumption falls to 19 TWh in 2050, a reduction of 32% from 2019 as a result of the switch to more efficient heating methods (see Figure 16 in the annex for the breakdown).

Across the time period, the oil and coal heated properties switch to the alternative options at the historical replacement rate of 6.44% per year. On average, 64.2% of consumers switch to LPG boilers with biopropane being used in all of these systems in 2040, 35.5% to air source heat pumps and 0.3% to hybrid systems. This translates to an estimated additional 460,368 homes heating using LPG/biopropane by 2050 and to 2,124 homes using an LPG boiler in conjunction with a heat pump as part of a hybrid system.

These proportions are based on the cost-effective (lowest levelised cost) technology being selected by consumers in each year and for the different housing archetypes. The analysis shows that from this cost-driven perspective on consumer decision making there would be no uptake of direct electric panel heaters or biomass boilers, largely explained by high fuel costs and high upfront costs, respectively.

A small selection of the levelised cost from the many archetypes and years analysed across the technologies is shown in Table 2. It highlights the trend shown in the analysis that in older homes, significant renovations are needed to make heat pumps a suitable solution and opting instead for LPG/biopropane offers a route where this high cost and disruption is not needed.

	Levelised Costs of Each Technology (2019, £/MWh)				
House Type	LPG	Biomass	ASHP	Direct Electric	Hybrid
Single family home, 1919-1944, no renovations	**86**	143	130	177	103
Single family home, 1919-1944, major renovations	89	130	**88**	180	100

Table 2: 2019 levelised cost comparison between the technology types for a single-family home built between 1919-1944 with no renovations and with major renovations.

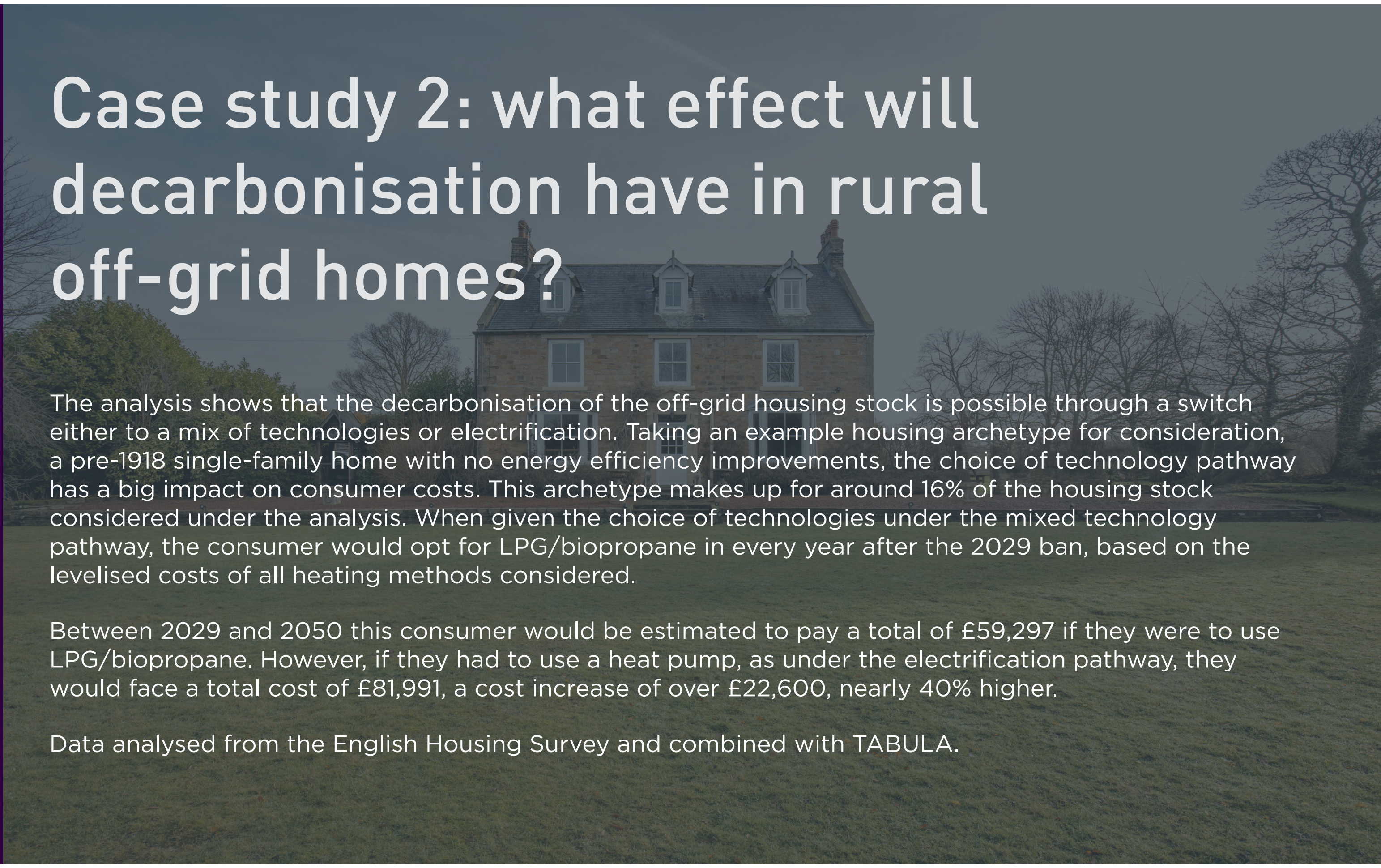
Through this switch to a mix of technologies based on the detailed levelised cost analysis outlined, emissions fall by 69% between 2019 and 2050 and reach 2.36 $MtCO_2e$ by 2050 under this scenario. This level is above still both target levels considered, meaning that more needs to be done if the UK Government is serious about reaching this level of change.

Conclusions from Scenarios 2a and 2b

The reductions achieved in both Scenarios 2a and 2b are not sufficient to meet either the minimum net-zero off-grid target of 1.4 $MtCO_2e$ or the further potentially necessary target of 0.61 $MtCO_2e$ in 2050, as shown in Table 3.

	2050 Emissions ($MtCO_2e$)	Reduction in emissions across pathway	Are the emission reduction targets met?
1. Business as Usual	6.62	15%	✗
2a. Electrification	1.91	75%	✗
2b. Mixed Technology Switch	2.24	71%	✗

Table 3: Summary of scenario outputs for BAU, Electrification and the Mixed Technology Switch



Case study 2: what effect will decarbonisation have in rural off-grid homes?

The analysis shows that the decarbonisation of the off-grid housing stock is possible through a switch either to a mix of technologies or electrification. Taking an example housing archetype for consideration, a pre-1918 single-family home with no energy efficiency improvements, the choice of technology pathway has a big impact on consumer costs. This archetype makes up for around 16% of the housing stock considered under the analysis. When given the choice of technologies under the mixed technology pathway, the consumer would opt for LPG/biopropane in every year after the 2029 ban, based on the levelised costs of all heating methods considered.

Between 2029 and 2050 this consumer would be estimated to pay a total of £59,297 if they were to use LPG/biopropane. However, if they had to use a heat pump, as under the electrification pathway, they would face a total cost of £81,991, a cost increase of over £22,600, nearly 40% higher.

Data analysed from the English Housing Survey and combined with TABULA.

Scenario 3a: Electrification (Rapid Replacement) Pathway

Under this scenario, the need for consumers to replace their existing heating system at a faster rate has been reflected through a 'rapid' replacement rate of 19%. Other than this, the framing of this scenario remains the same as Scenario 2a – with a 2029 ban on new heating oil and coal boilers leading to uptake of electric heat pumps (ASHP) as a replacement technology over time.

Final energy consumption is significantly reduced by 2050 to 0.24 TWh (see Figure 18 in the annex). This means that under this scenario a higher number of homes switch to heat pumps than under the historical replacement rate, and due to the relative efficiency improvement of heat pumps results in a greater fall in consumption to 10.8 TWh, a 61.5% reduction on 2019 levels (see Figure 7).

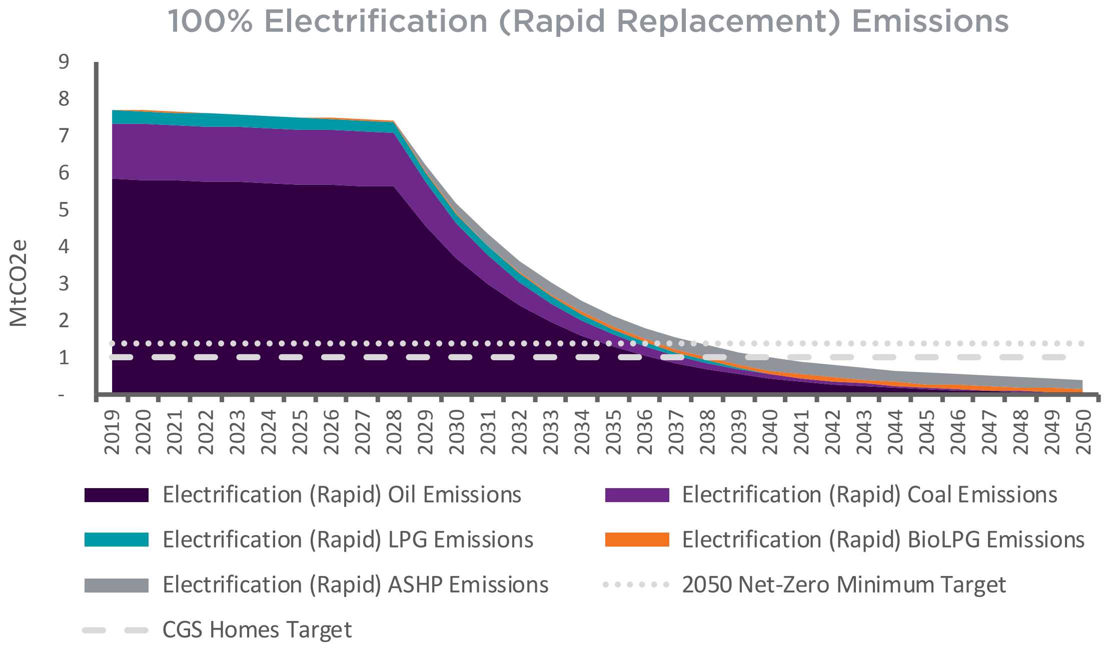


Figure 7 - rapid electrification scenario emissions for off-grid homes currently heating using oil, coal and propane ($MtCO_2e$)

Figure 7 shows that significant decarbonisation is achieved under this scenario, enough to meet both targets and reduce emissions in 2050 to below the levels stated as potentially necessary to comply with net zero. Emissions fall by 94.7% between 2019 and 2050 to 0.41$MtCO_2e$, below the illustrative CGS target of 1.02 $MtCO_2e$.

However, an absolute switch to 100% heat pumps has some substantial challenges and disadvantages. The mixed technology approach is also therefore considered.

Scenario 3b: Mixed Technology Switch (Rapid Replacement) Pathway

The Mixed Technology Switch (Rapid Replacement) pathway follows the same process as that of Scenario 2b, apart from the replacement rate being increased to 'rapid' rate of 19% per annum. This means that consumers still switch away from oil and coal to the alternative choices at the same proportions as under the previous mixed technology switch scenario with the historical replacement rate.

Consumption falls by 55% between 2019 and 2050 under this scenario, reaching a level of 17 TWh. At this level, an estimated 586,000 of the homes previously heated using oil and coal would be using biopropane as well as around 2,700 using hybrid heating systems through a combination of LPG boilers fuelled with biopropane and heat pumps.

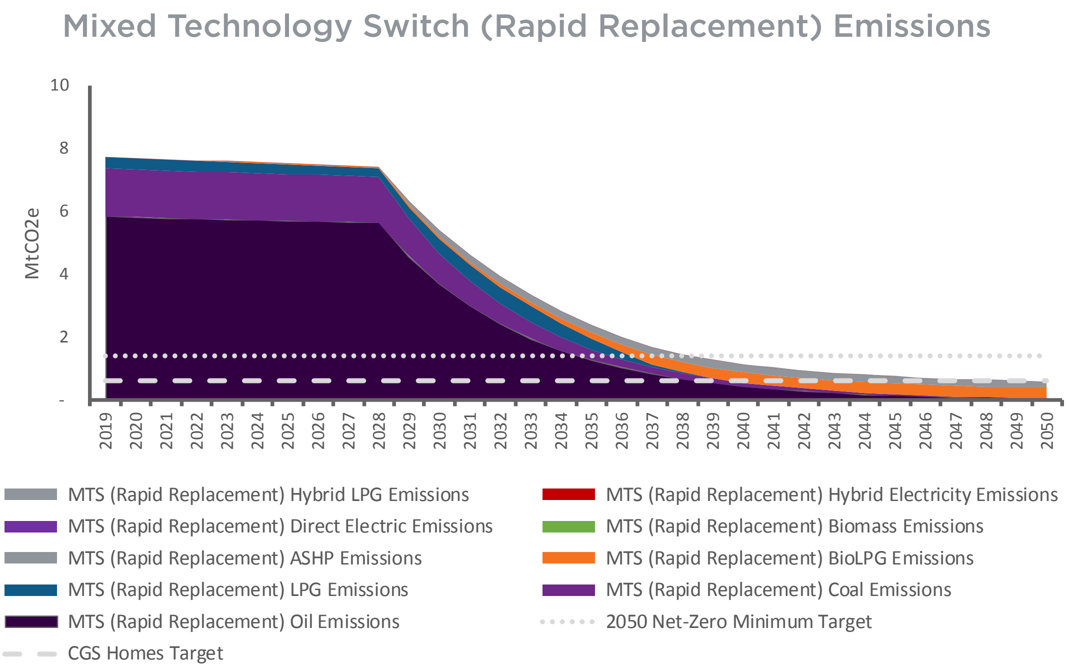


Figure 8 - rapid mixed technology switch emissions for off-grid homes heating using oil, coal and propane in 2019 ($MtCO_2e$)

Figure 8 shows that the emissions reductions under this scenario are enough to meet both the net-zero target for total off-gas emissions and the more ambitious CGS target. Here, a mixed technology solution can be consistent with the Government's decarbonisation objectives. Under this scenario, 2050 emissions are 0.96 $MtCO_2e$, a reduction of 88% on 2019 levels and below the stretch target of 1.02 $MtCO_2e$.

	2050 Emissions ($MtCO_2e$)	2019-2050 Emission Reduction	Are the emission reduction targets met?
1. Business as Usual	6.62	15%	✗
2a. Electrification	1.91	75%	✗
2b. Mixed Technology Switch	2.24	71%	✗
3a. Electrification (Rapid Replacement)	0.39	95%	✓
3b. Mixed Technology Switch (Rapid Replacement)	0.81	90%	✓

Table 3: Summary of scenario outputs for BAU, Electrification and the Mixed Technology Switch

Under the mixed technology switch there are several housing archetypes, for which LPG/biopropane offers the cheapest levelised cost in every year up to 2050. This section of housing archetypes accounts for just over half of the total housing stock analysed, where consumers would face costs that are on average 37% higher under electrification than if allowed the choice between low-carbon heating technologies (see Figure 9). In the archetypes most suited to LPG/biopropane, this rises to just over 50%. This is clearly a large cost penalty that these consumers would have to endure under an electrification pathway that is avoided under the mixed technology route.

Furthermore, an electrification route would place considerable additional demands on the electricity grid. This may mean that significant network upgrades are necessary in order to cope with a rise in peak power demand. When taking into account account these extra costs, consumers could face costs on average 37% higher for those homes which would switch to LPG/biopropane in each year considered (see Figure 9), but instead are forced to use electric heating[5].

In rural areas, which are less densely populated, these network improvement costs could potentially be even higher per property. With limited resources, network companies must consider which infrastructure investments are most valuable based on a cost benefit analysis.

The mixed switch gives consumers a choice of heating systems, which could help to bolster the replacement rate of fossil fuel heating and allow consumers a fair choice for a renewable heating system that suits them. A mixed technology approach offers flexibility to consumers that could therefore be valuable throughout the decarbonisation process, especially as it has been shown through Scenarios 3a and 3b that an increased rate of replacement is likely needed for the 2050 target levels to be met.

Conclusions from Scenarios 3a and 3b

Scenarios 3a and 3b show that with an increased rate of replacement, emissions from off-grid homes currently heated by fossil fuels can reduce to align with the net-zero target, as shown in Table 3. Both scenarios – including the mixed technology approach – are aligned with the emission targets.

Consumer cost is a crucial metric to compare between scenario 3a and 3b – both of which satisfy emission constraints. The analysis shows that the mixed technology scenario is lower cost to the consumer.

This is particularly the case for those that live in older, poorly insulated homes who face a considerable cost penalty if an electrification pathway was taken over a mixed technology switch.

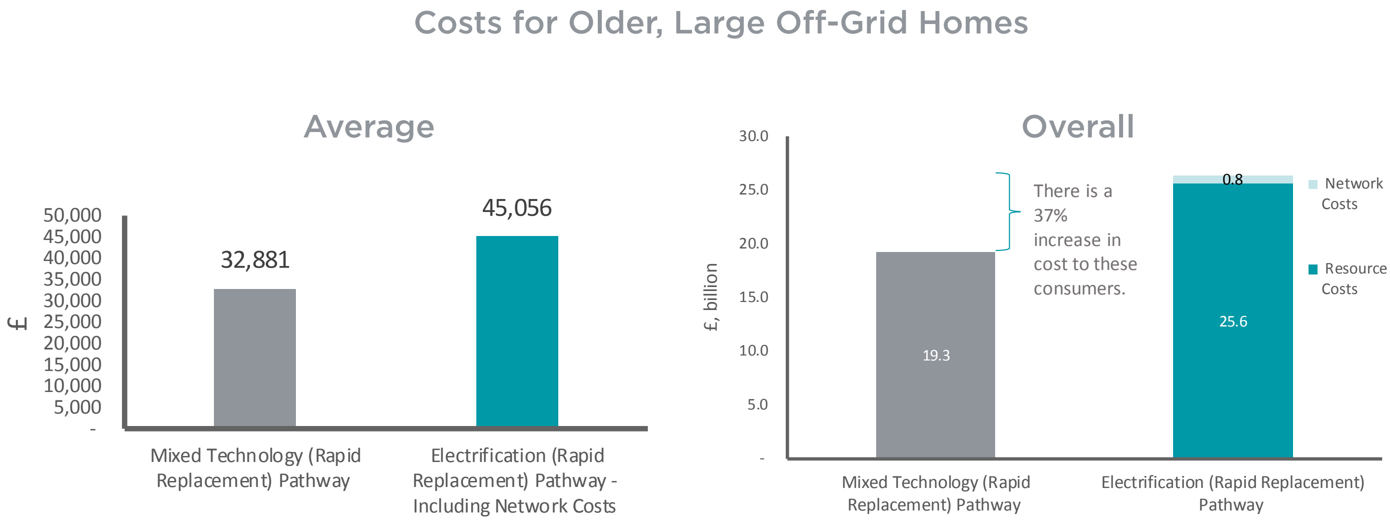


Figure 9 - Cost comparison between pathways for older, poorly insulated properties

Equally, the analysis shows that electric heat pumps should play an important role in the off-gas grid technology mix over the coming decades but are not the silver bullet for heat decarbonisation across all building types.

Government must now develop policy that supports decarbonisation pathways for low carbon fuels , such as bioLPG and other low carbon solutions. By setting a long-term policy framework that supports a consumer led, market approach to off-grid decarbonisation, the UK Government and Devolved Governments can enable a mix of environmentally progressive and innovate solutions for homes. This will empower UK citizens to make low carbon, sustainable choices that work for them, irrespective of their socio-economic status. A mixed technology approach can deliver deep decarbonisation at lowest cost, whilst supporting consumer choice and taking account of building variations.

The costs of inaction and impact of dangerous climate change is likely to be large. To take account of the value of greenhouse gas emission reductions, Figure 10 includes the UK Government's non-traded social cost of carbon estimates to show that the preferred mixed-technology scenario (3b) is lower in cost than business as usual viii. In other words, Government should support a mixed technology approach to off-grid heat decarbonisation.

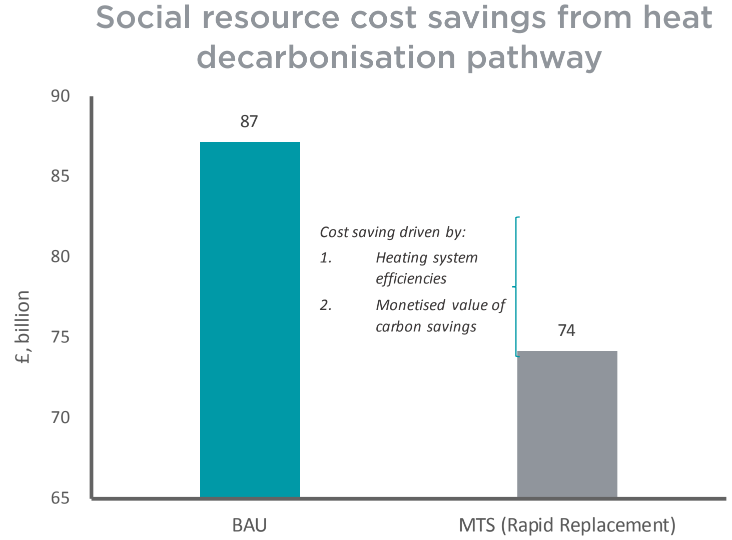


Figure 10 – Total costs of Business as Usual versus the Mixed Technology Switch with a rapid replacement rate (£bn)

Sensitivity Analysis: Consumer Preferences

In the mixed technology switch scenarios (2b and 3b), consumers are modelled to make the decision between heating system purely based on the levelised cost of each of the technology options. Whilst cost does have a large influence on the choices that consumers take, there are also 'intangible' factors outside of costs that affect the choices consumers make.

These intangible factors represent characteristics which are difficult to quantify but have an influence in decision making. These can include familiarity with a technology or social acceptability, as well as those more subtle factors which may also influence the choices of consumers.

To account for these preferences, we have analysed a sensitivity, which considers these intangible factors for each technology, to produce a 'generalised levelised cost'[29]. With consumers making decisions based on this generalised levelised cost instead, they would switch almost entirely to LPG/biopropane (99.7%), with a similar proportion for hybrids (0.3%) as before. This clearly shows the importance of familiarity in consumer decision making. **In the near term and particularly after system breakdown, consumers typically want systems which they understand and have a history of using.** Biopropane therefore offers a great fit for both consumer familiarity at the same time as providing renewable heating. The low carbon emissions combined with the drop-in nature of biopropane means that both benefits can be realised as part of the decarbonisation of heat.

It should be noted that consumer preferences are likely to adjust over time. For example, as young homeowners choosing their own heating systems for the first time come on to the market, they may be more open to different types of heating. Additionally, consumer preferences also vary considerably from person to person, meaning heterogenous choices are made, though this was beyond the scope of the homogenous consumers considered in this analysis.

In the near term and particularly after system breakdown, consumers typically want systems which they understand and have a history of using.

Key messages

1. High carbon fossil fuel heating will need to be phased out over the coming years. The Government has recognised this in the Clean Growth Strategy, but without policy intervention it is unlikely that emissions will fall by enough to align with a net-zero scenario by 2050.

2. A mixed technology switch allows a flexible approach to meeting decarbonisation targets reflecting the needs of the consumer. There is no silver bullet for the decarbonisation of off-grid heat. Instead, a mix of low carbon heating alternatives will mean that consumers can tailor their choice of system according to their preferences and property types, allowing better choice versus a single technology approach.

3. This is especially important as replacement rates will need to increase compared to historical levels for the targets to be met, by allowing as much choice as possible the likelihood of this increases.

4. The UK Government needs to develop policy incentives that support a mix of low carbon solutions, including biopropane (bioLPG). This analysis shows a role for biopropane in standalone boilers and as part of hybrid systems with an electric heat pump.

Annex: Scenario Graphs

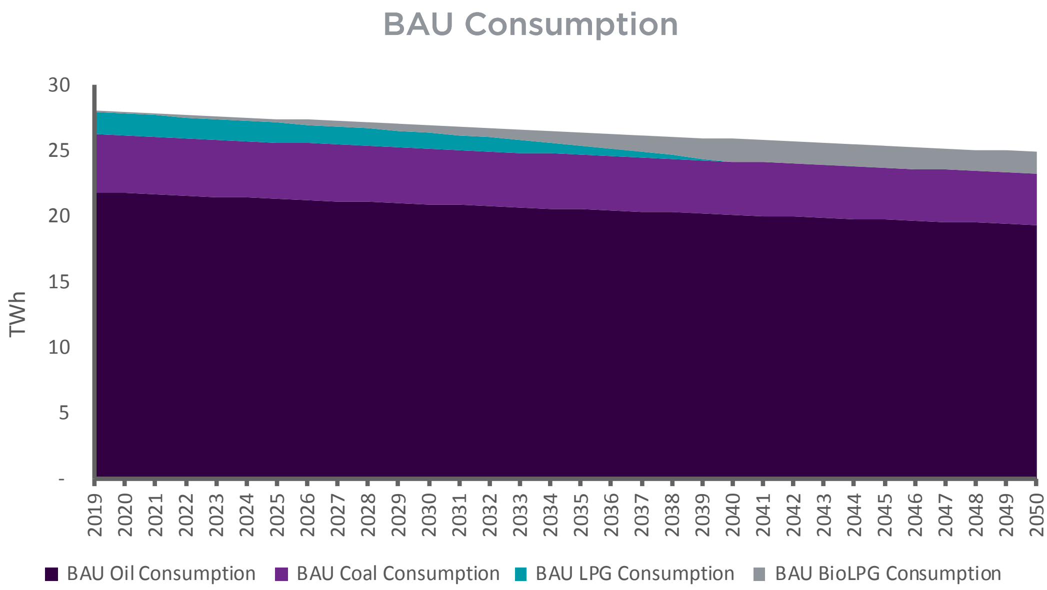


Figure 11 - Business as Usual (BAU) scenario fuel consumption for off-grid homes currently heating using oil, coal and propane (TWh)

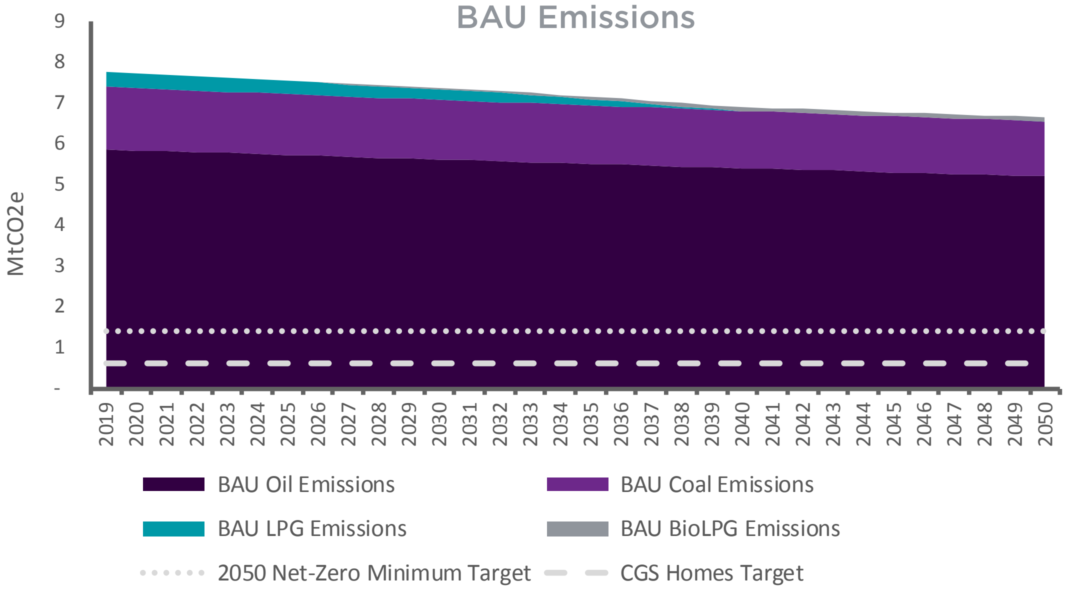


Figure 12 - Business as Usual (BAU) scenario emissions for off-grid homes currently heating using oil, coal and propane ($MtCO_2e$)

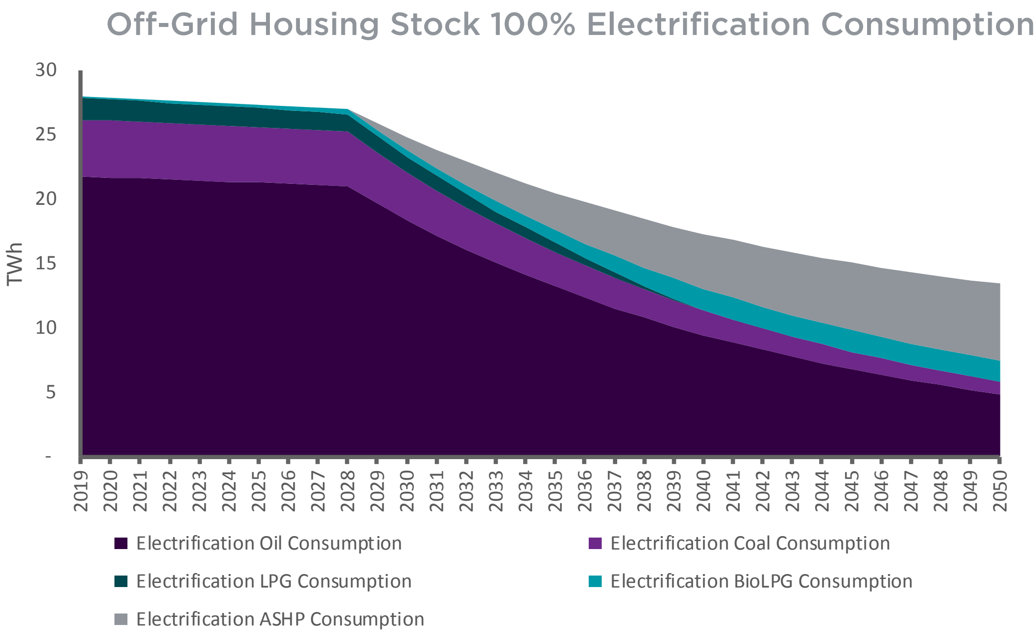


Figure 13 – Scenario 2a final energy consumption (TWh)

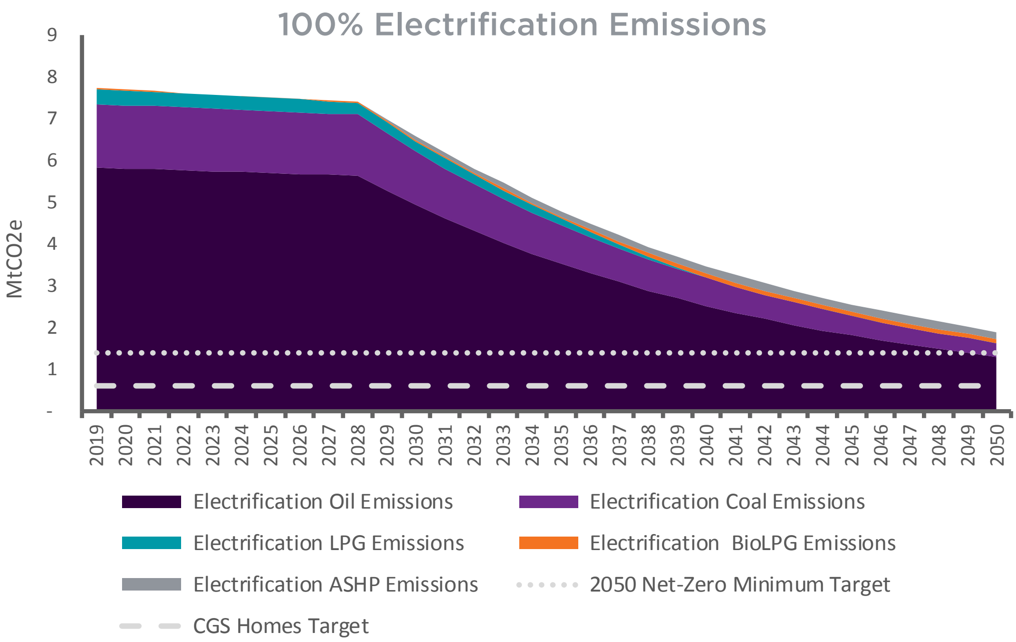


Figure 14 – Scenario 2a greenhouse gas emissions ($MtCO_2e$)

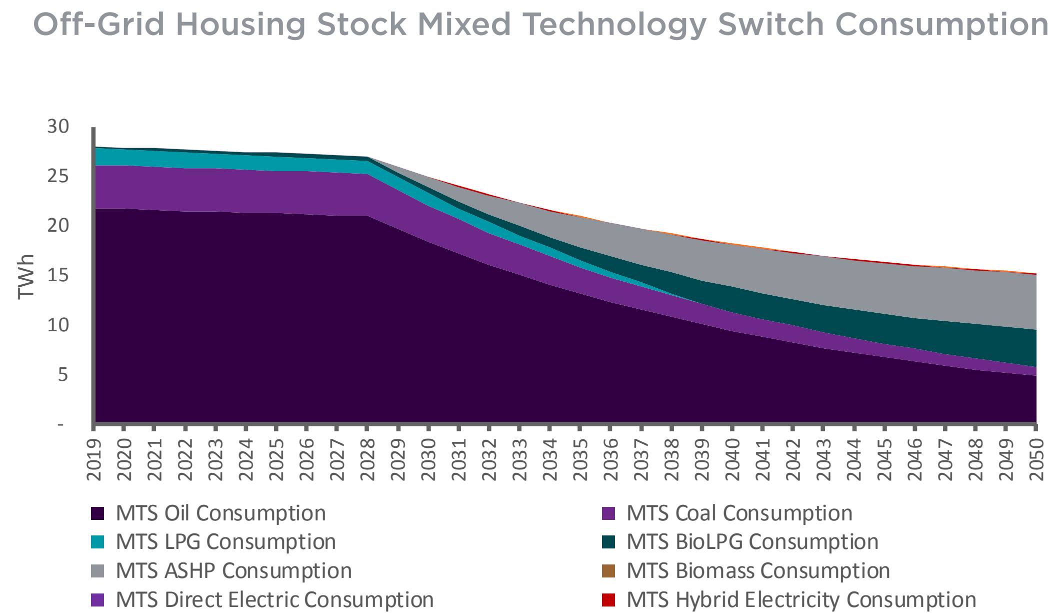


Figure 15 - Scenario 2b final energy consumption (TWh)

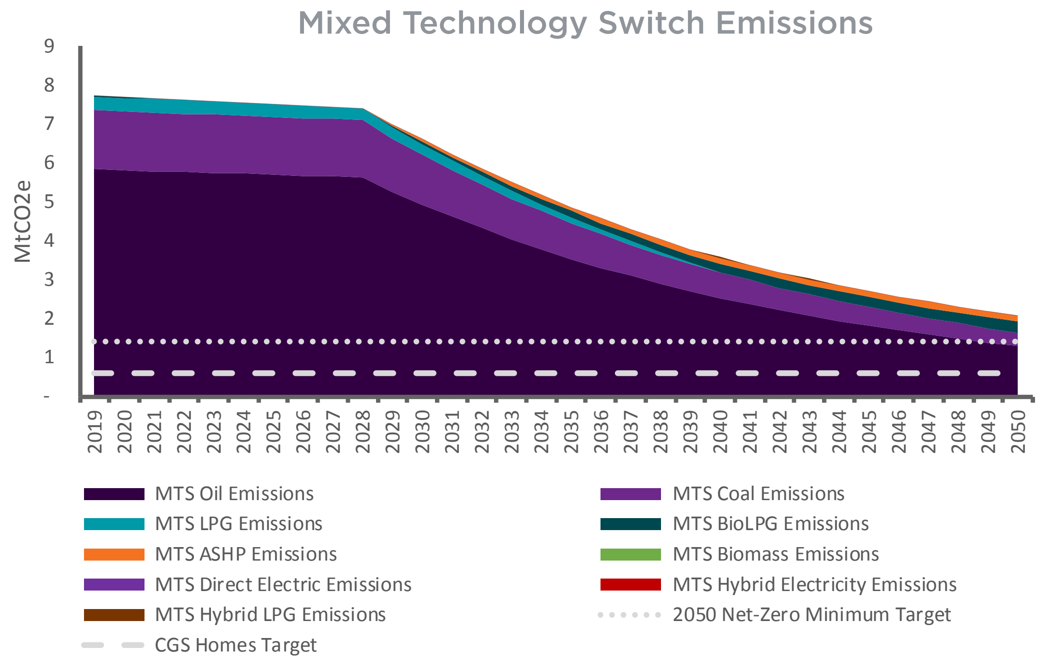


Figure 16 - Scenario 2a greenhouse gas emissions ($MtCO_2e$)

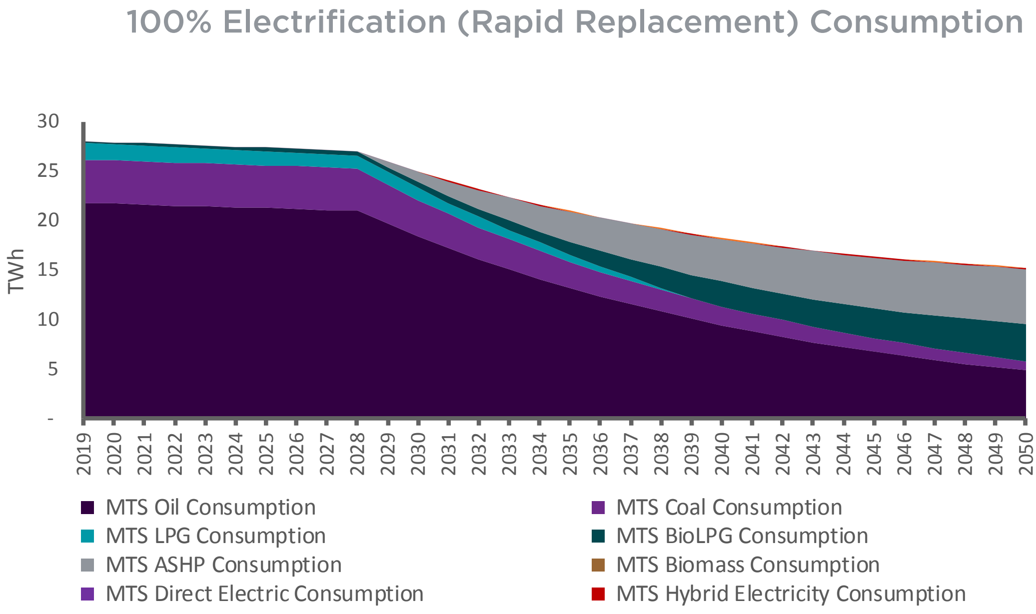


Figure 17 – Scenario 3a final energy consumption (TWh)

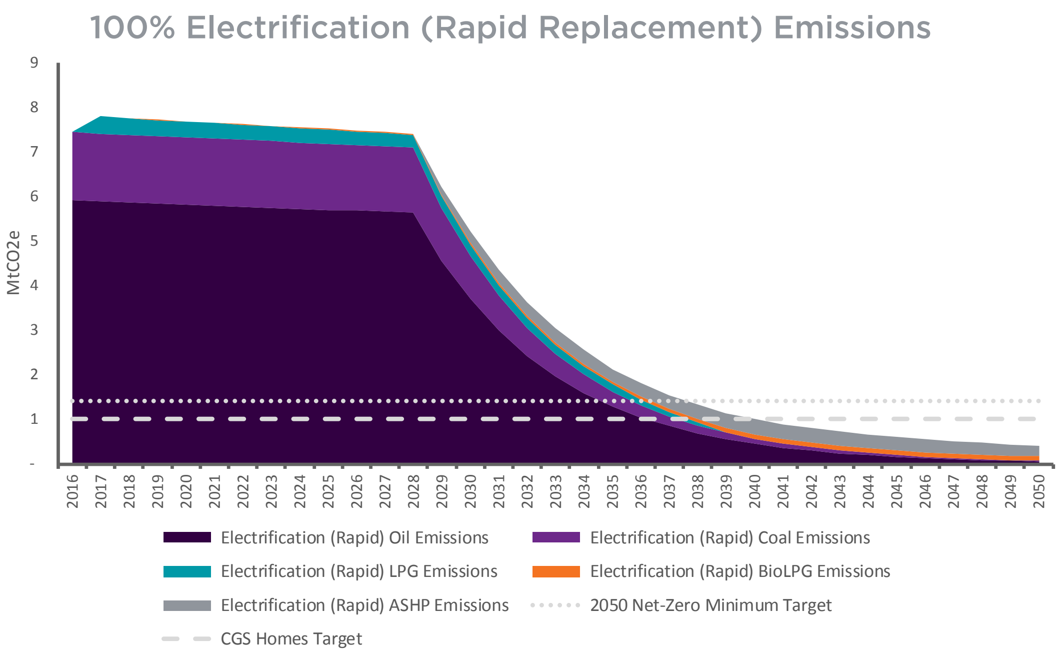


Figure 18 – Scenario 3a greenhouse gas emissions ($MtCO_2e$)

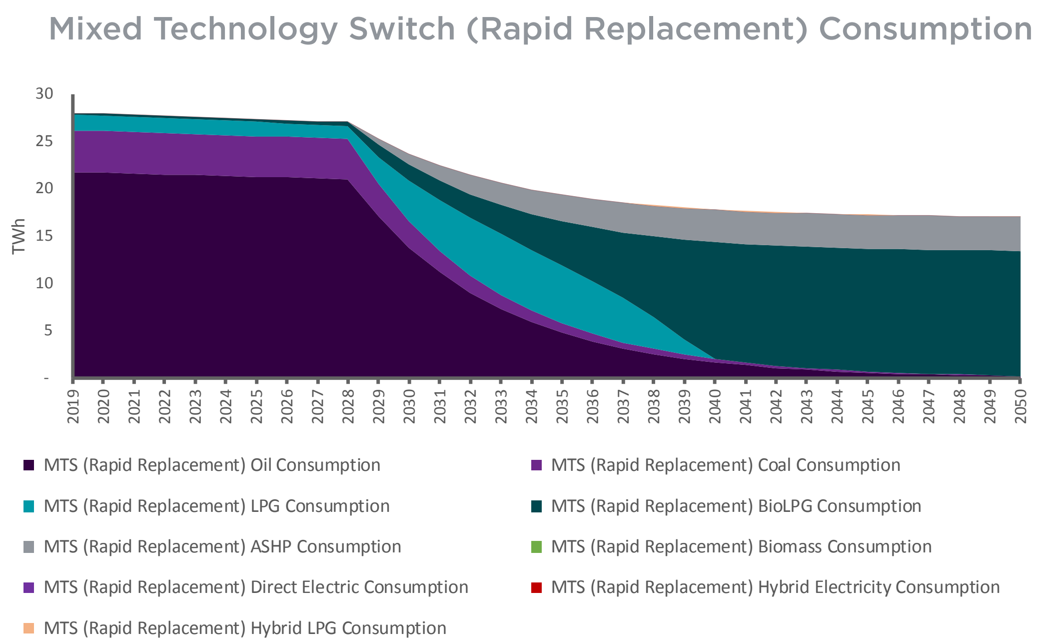


Figure 19 – Scenario 3b final energy consumption (TWh)

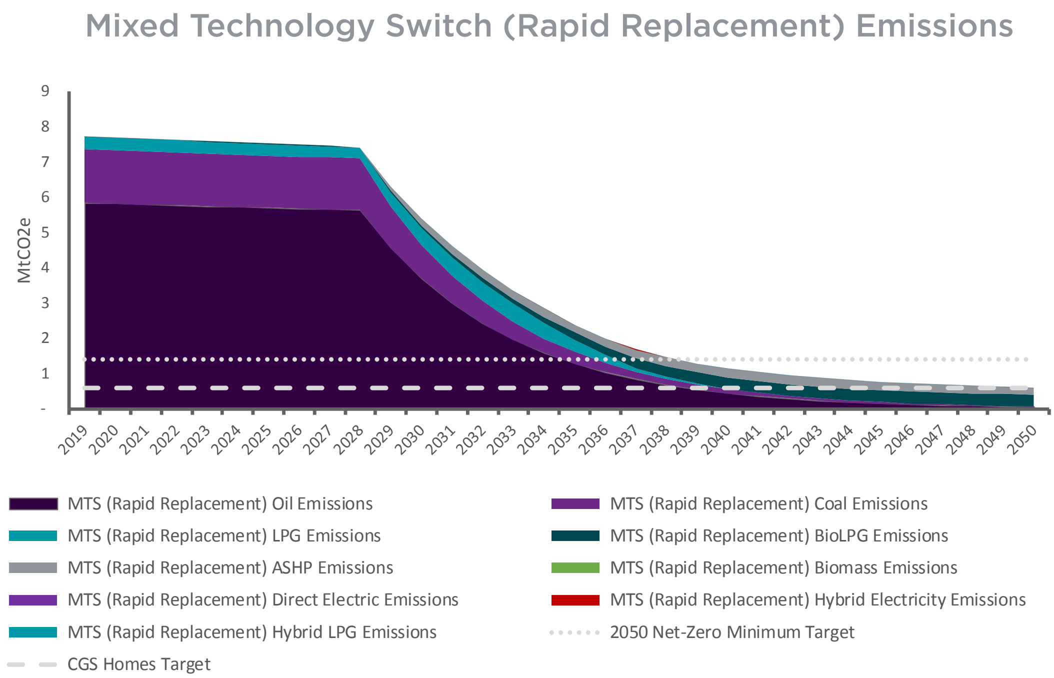


Figure 20 – Scenario 3b greenhouse gas emissions ($MtCO_2e$)

Annex: Key Modelling Assumptions

The analysis used throughout this report is built around data assumptions that form the inputs to the modelling process. The key modelling assumptions used are displayed below along with the sources of these assumptions. We have used credible data sources coming from neutral sources, such as BEIS and the CCC, where possible.

Capital Costs

Technology	Size	Value	Unit	Does this change up to 2050?	Source
Gas Condensing Boilers	12 kW	1500	£	No	BEIS
	13-15 kW	1600	£	No	BEIS
	16-18 kW	1700	£	No	BEIS
	19-24 kW	1900	£	No	BEIS
	25-28 kW	2000	£	No	BEIS
LPG Tank Rental		65	£/year	No	Household Quotes
Electric Panel Heater		200	£	No	Electric Heating Expert
Biomass Boilers	<10 kW	8120	£	No	BEIS
	11-15 kW	9534	£	No	BEIS
	16-20 kW	11544	£	No	BEIS
	21-25 kW	13650	£	No	BEIS
	26-30 kW	16574	£	No	BEIS
Radiator		273	£	No	Stelrad
Air Source Heat Pumps	3	5,770	£	Yes – 20% cost down applied up to 2030 in line with CCC assumptions	BEIS
	4	6,870	£		BEIS
	5	6,890	£		BEIS
	6	7,550	£		BEIS
	7	7,930	£		BEIS
	8	8,270	£		BEIS
	9	8,270	£		BEIS
	10	10,830	£		BEIS
	11	10,650	£		BEIS
	12	11,400	£		BEIS
	13	11,890	£		BEIS
	14	11,730	£		BEIS
	15	13,160	£		BEIS
	16	13,060	£		BEIS
	17	16,710	£		BEIS
	18	16,140	£		BEIS
	20	18,270	£		BEIS

Fuel Costs

Fuel costs have been taken from the Sutherland Tables for 2019 values. Due to the uncertainty and difficulty in predicting future fuel prices, we have assumed that these prices remain constant up to 2050.

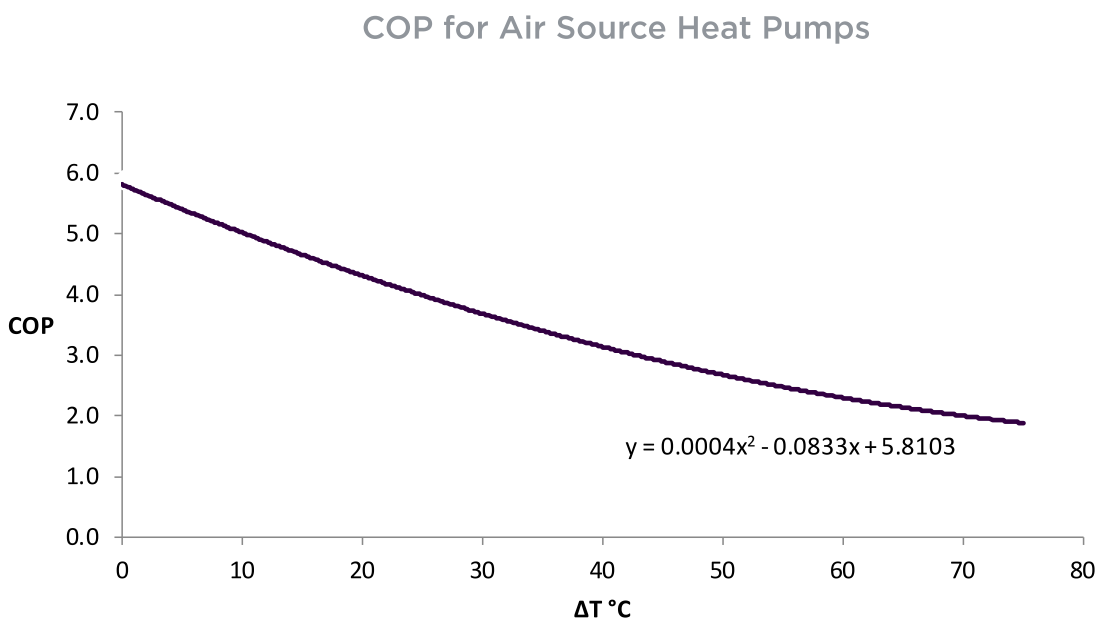
Biopropane is priced at an initial 10% premium over the conventional LPG price. This assumption is reflective of typical price premium and is assumed to reduce over time – tending towards the conventional LPG price – as the industry scales production to hit 2040 targets.

Heating Efficiencies

Technology	Value	Unit	Does this change up to 2050?	Source
Old-Existing Oil Boiler	0.75	COP	No	European Commission
Old-Existing Coal Boiler	0.75	COP	No	European Commission
Gas Condensing Boiler	0.92	COP	No	BEIS
Biomass Boiler	0.75	COP	No	BRE
Air Source Heat Pump	Ranges from 1.8 to 3.4 depending on house type.	SPF	No	Calculations completed for the analysis
Direct Electric Panel Heaters	1	COP	No	Assumption
Hybrid Heat Pump	3.2	SPF	No	Calculations completed for the analysis – similar to Element Energy average

Air Source Heat Pump Efficiencies

The air source heat pump efficiency has been modelled based on the specification given for a Vitocal 35-A Viessmann. Typically, it can be said that the smaller the temperature change required from a heat pump, the higher the efficiency. Accordingly the analysis has considered the typical monthly temperatures across the UK, taking Leeds as a typical climate of the UK, based on data provided by Ashrae Meteo. This was used to calculate the heating requirements in each month, in terms of the temperature increase that was needed (to reach a target level of 20OC) and the number of days where heating would be required. From this a calculation for the COP of heat pumps for each month was weighted by the heat output requirement each month to work out an average heat pump performance in each of the 48 housing archetypes. The graph below shows the equation that we have used for these calculations.



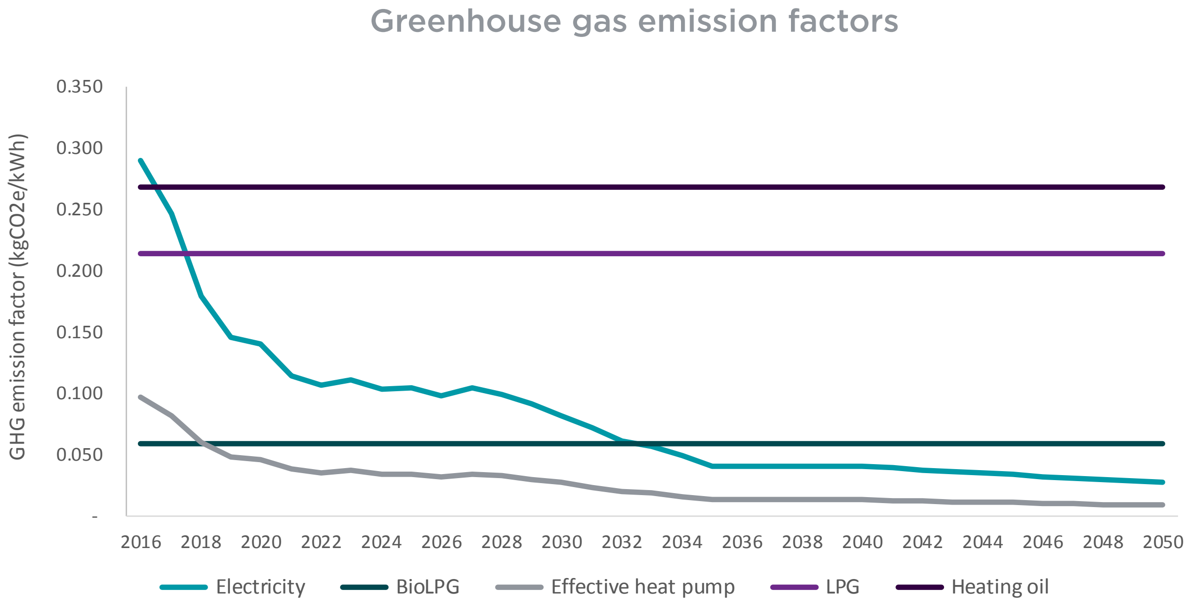
Using this process, the efficiency of the heat pumps ranged from 1.8 to 3.39 across the housing types.

Technology	Value	Unit	Does this change up to 2050?	Source
Oil Boiler	15	Years	No	BEIS
Coal Boiler	15	Years	No	BEIS
Gas Condensing Boiler	15	Years	No	BEIS
Biomass Boiler	15	Years	No	BEIS
Air Source Heat Pump	18	Years	No	CCC
Direct Electric Panel Heaters	15	Years	No	BEIS
Hybrid Heat Pump	15	Years	No	CCC

Carbon Emission Factors

The below graph illustrates the emission factor assumptions used in the analysis – with the effective heat pump line included for illustrative purposes only. Data is taken from DEFRA and BEIS and includes a projected decrease in the electricity emission factor to 2050.

Biopropane is not currently featured in the DEFRA emission factor table. Instead, the official French Government (ADEME) emission factor assumption is used (0.06 $kgCO_2e/kWh$). This is reflective of the academic literature (e.g. Biofuels, Bioproducts and Biorefining article) and a typical emission factor, though this could be decreased or increased depending on biopropane production process and feedstock.



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