Off-Grid Customer Research

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Prepared For

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Executive Summary

Although robust estimates are currently lacking, there are believed to be circa 2,000 properties across the UK that are 'off-grid', meaning they do not have an electricity or mains gas connection. A range of socio-economic challenges are faced by people living 'off-grid', including being at greater risk of fuel poverty (struggling to afford to adequately heat their homes). Therefore, there is a need for Distribution Network Operators (DNOs) and Gas Distributions Networks (GDNs) to understand the very specific realities and practicalities of reducing the greenhouse gas emissions associated with off-grid properties and the likely impacts on occupants.

Given the global push to reach net zero targets, it is becoming increasingly necessary to decarbonise off-grid properties, indeed we are unlikely to be able to achieve net zero in the UK without doing so. This is also essential to avoid off grid homes becoming 'stranded assets' that are still dependent on increasingly expensive fossil fuels, once much of the rest of the country has transitioned to low carbon sources.

The focus of the project is on homes that are 'off grid' (either completely off the gas and electricity grid or off the gas grid) in the North of England, which fall under the jurisdiction of Northern Powergrid (NPG - electricity infrastructure) and Northern Gas Network (NGN) and are primarily focused on the three following broad geographical locations, where concentrations of off grid home are found:

- Cumbria
- North Yorkshire
- Northumberland

The Energy Innovation Centre (EIC), in partnership with NGN and NPG have commissioned Thornton Tomasetti (TT) and the Centre for Regional Economic and Social Research (CRESR) (operating as an equal partnership) to research and understand the realities and practicalities of decarbonising off grid properties (both single properties and groups). The project combines the technical, regulatory and commercial practicalities of implementing decarbonisation solutions based on a detailed understanding of the lived experience of off grid living for households and how they are likely to respond to retrofit.

As part of this research, 13 interviews were conducted with sector stakeholders and 24 interviews were conducted with occupants of off-grid homes, either completely off-grid or off the gas grid. Each household also completed a questionnaire about their current and likely future energy needs and any retrofit activities undertaken to date. This report presents the findings of the interviews, surveys and 6 composite case studies generated from the gathered data and representing a range of off grid living scenarios. For each case study presented, a decarbonisation framework was applied, accounting for various social, economic, and technical constraints, in conjunction with energy modelling and analysis, to identify appropriate decarbonisation options for each case study. The options were then presented to the interview participants, and feedback was collected, leading to refinement of the options.

The research and decarbonisation assessment identified a number of common findings:

- Occupants are more likely to improve the efficiency of the house with the suggested retrofits (either partial or full retrofits) prior to implementing the decarbonisation options.

- The majority of households that are not currently connected to the gas grid, have little desire to connect to it. Most are, however, eager to secure a reliable electricity supply, whether this is through a grid connection or other reliable source. In many cases the distance from the property to the nearest grid connection point renders a new connection cost-prohibitive and unfeasible.

    - For those households that have challenges with continuous energy supply (i.e. have frequent black-outs) grid independence is also a desirable option as it would provide much needed resilience for the household.

- There is a drive towards the electrification of assets; as fuel prices rise and there is a further drive for carbon neutrality, 'green' electricity is becoming more desirable for households.

- Off-grid communities are willing to consider community-based energy schemes, provided that they are in-keeping with surroundings, financially viable and offer network resilience.

- Whilst environmental sustainability is important to many of the households we spoke to, the viability of a decarbonisation solution is dependent on financial feasibility, this is especially important for less affluent households.

  - Improved access to grants and increases in the amounts available (i.e. an increase in the value of the Boiler Upgrade Grant), or other forms of funding, would likely increase uptake in decarbonisation options.

- Some wealthier households were attached to their current ways of doing things, such as continuing to burn wood and run a diesel generator. There was a sense of security in what was familiar and considered 'low risk'.

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Revision History

Revision	Date	Document Ref.	Comments
Issue 1	07/04/2025	MA23045-R01 Issue 1	For comment

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Acronyms & Abbreviations

Acronym or Abbreviation	Definition
AONB	Areas of Outstanding Natural Beauty
BESS	Battery Energy Storage Systems
CRESR	Centre for Regional Economic and Social Research
DNO	Distribution Network Operator
EIC	Energy Innovation Centre
EV	Electric Vehicle
GDN	Gas Distributions Network
HAWT	Horizontal Axis Wind Turbine
HESS	Hydrogen Energy Storage Systems
HVO	Hydrotreated Vegetable Oil
MCS	Microgeneration Certification Scheme
NGN	Northern Gas Networks
NPG	Northern Powergrid
PV	Photovoltaics
ROI	Return on Investment
SAP	Standard Assessment Procedure
TRL	Technology Readiness Level
TT	Thornton Tomasetti
VAWT	Vertical Axis Wind Turbine

1.0 Introduction and Project Overview

Although robust estimates are currently lacking, there are believed to be circa 2,000 properties across the UK that are ‘off-grid’, meaning they do not have an electricity or mains gas connection. A range of socio-economic challenges are faced by people living ‘off-grid’, including being at greater risk of fuel poverty (struggling to afford to adequately heat their homes). Therefore, there is a need for Distribution Network Operators (DNOs) and Gas Distributions Networks (GDNs) to understand the very specific realities and practicalities of reducing the greenhouse gas emissions associated with off-grid properties and the likely impacts on occupants.

Given the global push to reach net zero targets, it is becoming increasingly necessary to decarbonise off-grid properties, indeed we are unlikely to be able to achieve net zero in the UK, without doing so. This is also essential to avoid off grid homes becoming ‘stranded assets’ that are still dependent on increasingly expensive fossil fuels, once much of the rest of the country has transitioned to low carbon sources.

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As part of this research, 13 interviews were conducted with sector stakeholders and 24 interviews were conducted with occupants of off-grid homes, either completely off-grid or off the gas grid. Each household also completed a questionnaire about their current and likely future energy needs and any retrofit activities undertaken to date. This report presents the findings of the interviews, surveys and 6 composite case studies generated from the gathered data and representing a range of off grid living scenarios. For each case study presented, a decarbonisation framework was applied, accounting for various social, economic, and technical constraints, in conjunction with energy modelling and analysis, to identify appropriate decarbonisation options for each case study. The options were then presented to the interview participants, and feedback was collected, leading to refinement of the options.

2.0 Decarbonising Off-Grid Homes: Key Findings from Qualitative Interviews

This report draws on 24 energy surveys and interviews with occupants of off-grid homes, either completely off-grid or off the gas grid. It also builds on insights from 13 interviews with sector stakeholders. Participants represented a diverse range of experiences: homeowners and renters (private and social), rural and urban fringe, families and single households, older and younger, living in old and modern homes and using a range of heating solutions from solid fuel burners and oil boilers to modern heat pumps and storage heaters. The interviews represent mainly people with an interest in decarbonisation; possibly reflecting a situation where it is difficult to recruit those uninterested in the environment to a study of this nature. Although it is important to note that many participants were attracted to the study by their concerns about energy affordability and energy security.

Table 1: Summary of interview participants.

Location	Number of Occupants	Tenure
Cumbria	5	Homeowner
Cumbria	2	Homeowner
Cumbria	4	Homeowner
Cumbria	1	Homeowner
Cumbria	3	Private Rent
Cumbria	3	Homeowner
Cumbria	2	Private Rent
Cumbria	2	Homeowner
Northumberland	1	Social Rent
Northumberland	2	Social Rent
North Yorkshire	2	Homeowner
North Yorkshire	2	Homeowner
North Yorkshire	2	Homeowner
North Yorkshire	2	Homeowner
North Yorkshire	2	Homeowner
North Yorkshire	2	Homeowner
North Yorkshire	2	Homeowner
North Yorkshire	2	Social Rent
North Yorkshire	2	Social Rent
North Yorkshire	5	Social Rent
North Yorkshire	1	Social Rent
North Yorkshire	2	Social Rent
North Yorkshire	3	Social Rent

2.1 Social Considerations and Barriers to Decarbonisation

We found that affordability is by far the most important consideration for decarbonisation (both upfront costs and ongoing running and maintenance costs): changing the energy system in the home is perceived as expensive, while grants and financial incentives were inaccessible or considered inadequate. Very few participants, despite striving for greater sustainability in many cases, were willing to pay for more sustainable solutions. The majority can only justify pursuing decarbonisation if it will make energy more affordable or financially attractive. Having said that, participants were generally uninterested in gas connection even if it was feasible, due to concerns about sustainability and the work involved in central heating installation - it was widely recognised that natural gas cannot have a long-term future in the UK if we are to strive for net zero.

We also found that access to expert knowledge on decarbonisation solutions is scarce, especially for those living fully off grid. Participants struggled to find tradespeople who could offer expert advice and deliver high quality installation and maintenance work. Those living off grid generally had good technical awareness and were familiar with many options we discussed with them – their choices or preferences were, in most cases, well informed.

Technology: Despite good technical awareness, some participants worried that new technology would too difficult to manage and adjust to (especially older people) or had concerns about new technologies (especially heat pumps and electric vehicles (EVs)), including those related to cost (installation, running costs and maintenance), noise, space taken up by the new system, the length and complexity of the installation process and its impact on the current structure or look of the home, as well as concerns that the technology is not developed or efficient enough, that it is not suitable for their needs (for example, there are no EVs readily available for farmwork), or that there is no infrastructure for EVs in the area.

The house itself often determined what solutions were considered: its location, age and condition, its size and special character – all of these factors were crucial when considering options. Some locations were unsuitable for renewables (too shady, surrounded by trees, subject to strict planning rules), some required very expensive and comprehensive work that would require residents to leave for a period of time and would negatively affect the garden or special period features. Sometimes these concerns were based on fact and sometimes perception.

Warmth: there were a range of attitudes towards warmth. Very few said they did not think about heating their house: the majority were very calculated in their energy use for heating, either for financial, technical or environmental reasons. Some take pride in tolerating relatively cold indoor temperatures and think people should ‘toughen up’, while others struggle with the cold, some due to disability or old age. It was rare for people to heat their homes beyond 19 °C and common for participants to warm their bodies, rather than the space by wearing more layers and using blankets and water bottles. At the same time, a significant proportion (14 out of 24) felt that their house met their energy needs as it is (partly reflecting recent works to fit homes with insulation and new heating systems in 11 out of these 14).

Interestingly, while professional stakeholders advocated for interim solutions such as biofuels, participants were not interested in this option: they did not want to invest in specific fuels when their burners were more versatile, and some could access ‘free’ wood from their land, which made their burner affordable.

Based on the qualitative interviews, the matrix shown in Figure 1 represents participants' position towards decarbonising, reflecting their responses to questions about their ability and willingness to decarbonise their homes.

Questions on ability included:

- Aspects of tenure-related agency
- Financial ability
- Planning considerations
- Technological compatibility

Questions on willingness included:

- Aspects of desire to decarbonise
- Concerns about disruption and the aesthetics of the house
- Level and intensity of warmth
- Trust in new technologies and existing habits

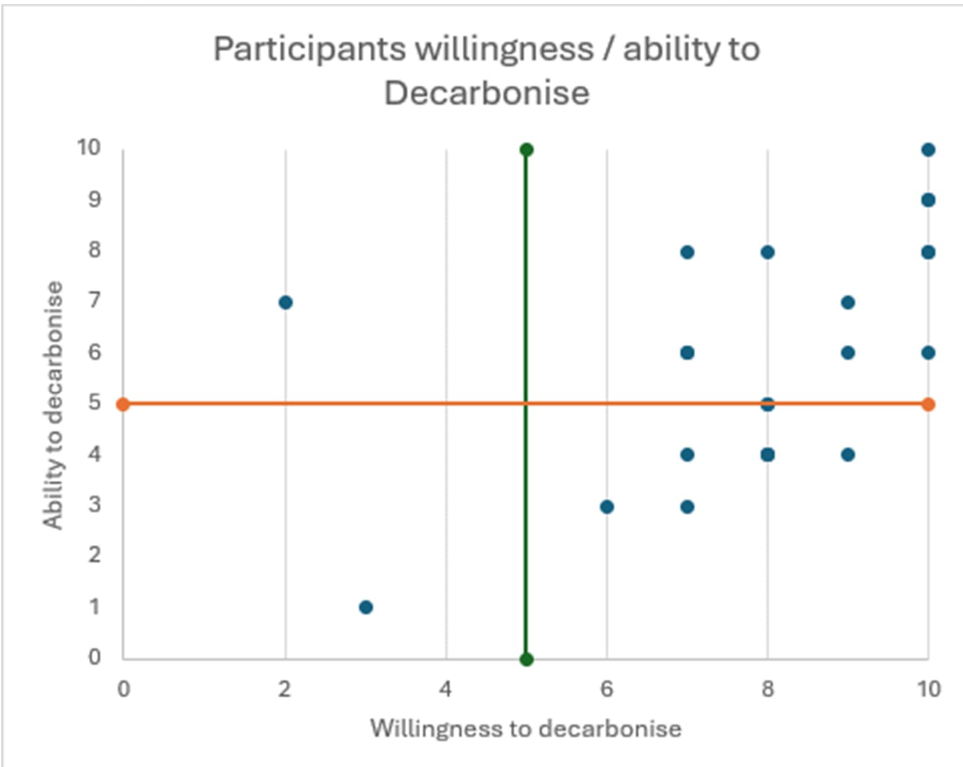

Figure 1: Participant willingness / ability quadrant based on the interviews conducted. Note that there were 24 respondents, but some occupy the same value on the graph.

3.0 Decarbonisation Assessment Method

3.1 Technical Constraints

Using the findings of interviews and assessment of the participant locations (using postcodes), a number of technical constraints for the decarbonisation and connection of off-grid properties were identified:

Proximity and feasibility of new connections; For households within 250 m of an existing gas connection point, the most cost-effective option is to connect the households in the area. Where locations have multiple households that are not connected to the gas grid, the cost per household can effectively be lowered using an in-fill scheme. An in-fill scheme requires a minimum of 30% of households within the area to partake in the new connection. For single, or few, households located further than 2 km from the nearest existing gas connection point, a new connection is likely not feasible and will not be the most-cost effective option. Similar schemes are also available for new electric connections. The point of connection must also have capacity for the household demand for the new connection to be feasible.

Planning / geographical constraints; Many off-grid households are located in rural areas, including Areas of Outstanding Natural Beauty (AONBs). An AONB is land protected by the Countryside and Rights of Way Act 2000 [1]. Any new utility service within the area must be approved by the local authorities or the Secretary of State and is often subject to more stringent regulations. Listed buildings also require planning permission for any significant works (such as solar photovoltaics (PVs) and wind turbines).

Size / area available; For a number of the properties included in the study, it is not feasible to install larger equipment, for instance a wind turbine, as there is insufficient land / space available to install the equipment or to maintain safety margins around the equipment. In addition to this, the accessibility to the planned installation area may not be feasible or requires a significant cost increase for installation.

Low solar radiation / wind speeds; Some properties are located in areas that have limited solar radiation or where wind speeds are insufficient to generate the energy required to sustain the property.

Building fabric / aesthetic; In some cases, the building fabric may not be suitable for the suggested equipment installation and may require structural enabling works and incur a significant cost increase. Households may also have an attachment to the current building aesthetic (and it may be protected by planning restrictions), and as such might not be willing to install prominent equipment.

Resilience; For some households with an existing electricity connection there are periods where there is no energy supply to the property. This is especially evident during severe weather events such as flooding or high winds, where the grid supply may be affected. Also, those who rely on bottled gas or diesel (for generators) delivered to their homes severe weather can interrupt deliveries.

3.2 Decarbonisation Framework and Energy Modelling

A framework previously developed by TT has been modified, with support from Cardiff University to support the assessment of the optimal decarbonisation options for each off-grid household, accounting for the constraints listed above. The framework is intended to guide the user, and each case should be reviewed individually.

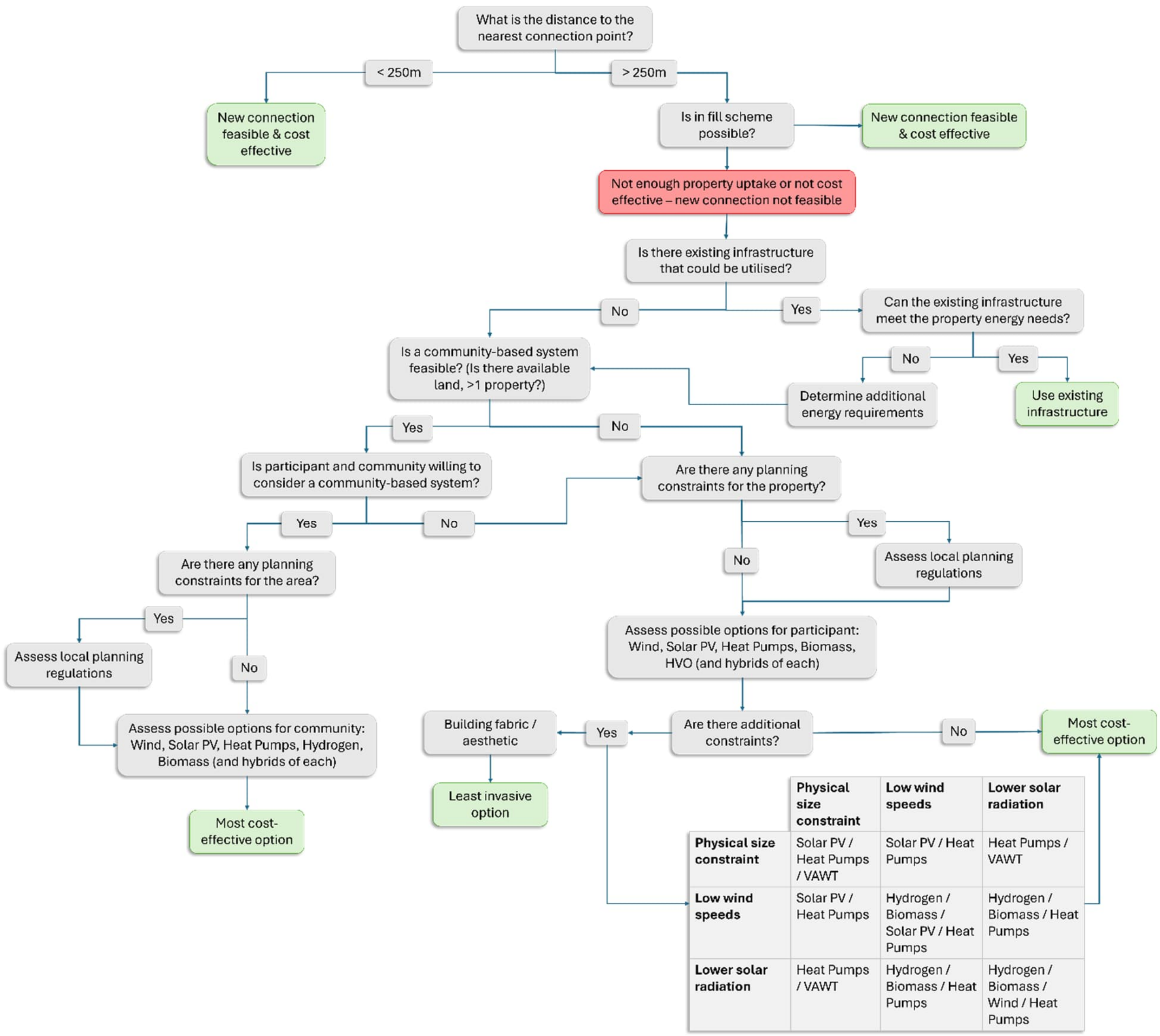

Figure 2: The decarbonisation option framework.[1]

It should be noted that consideration has been given to new connections at the start of the framework. NGN and NPG policy is to transition to 'clean energy' [2] [3], and a new connection may not be considered 'clean'. However, NGN acknowledges that entirely 'clean energy' sources are not feasible for the majority of properties at this stage, and an importance is placed on ensuring households are connected, especially

[1] New connections within this framework are not supply specific, and the framework can be applied to properties that are off the gas or electric grid, or completely off grid.

for households at risk of fuel poverty. NPG is transitioning to renewable energy sources, and a new connection would ultimately be supplied by renewable sources in the future.

For community-based schemes (microgrids), the scheme is only considered viable if the cost per household is deemed acceptable. For cases where the community scheme is not viable, the framework should be reassessed on a household basis.

The results of the interviews highlighted that a number of participants have already begun the journey to decarbonising their homes. For these properties the focus of the technical assessment was to support the modifications already completed, in order to ensure they are as efficient as possible, and where there is opportunity to do so, supplement the existing modifications with additional decarbonisation options.

For each story listed in Section 4.0, the decarbonisation framework was applied, in conjunction with energy modelling and analysis, to identify appropriate decarbonisation options.

The energy supply and demand for the site was modelled using a tool previously developed by TT for projects of similar energy demand and scale. A number of decarbonisation options were considered; Vertical Axis Wind Turbines (VAWTs), Horizontal Axis Wind Turbines (HAWTs), solar PV (both fixed and vertical), battery energy storage systems (BESS), hydrogen energy storage systems (HESS), biomass, and air / ground source heat pumps. Visual examples of each of these options are shown in Appendix B. For each decarbonisation option, the exact technology (i.e. brand and model) has not been reported, as the technology will need to be specific and designed for each property, for which the exact fabric details are currently unknown.

Note that only options with a high Technology Readiness Level (TRL) were considered for this project, this was to ensure that options suggested could be readily deployed and are representative of the current landscape.

Where community based schemes have been considered, future lifestyles have been accounted for. For instance, if it is believed that a community will likely use EVs in the future, this has been accounted for within the energy demand for the site, and the required capacity increase of the site. Infrastructure, such as charging points, have not been included within the assessment.

For a number of properties, the continuous supply of energy to meet the needs of households will not be met by the stated decarbonisation power supply options. In these cases, a form of energy storage should be considered to supplement the energy supply and provide resilience for the network. Two types of energy storage systems are considered for this assessment: BESS or HESS. Each storage system should be assessed and sized on an individual property basis, unless part of a community scheme.

It should be noted that the evaluation of each option was high level and only considered the direct carbon emissions of the option (i.e. did not consider the carbon emissions for the entire life cycle of each option). However, it is likely that if a decarbonisation option is deployed, the carbon emissions will be reduced compared to the current energy provisions, inclusive of the carbon emissions for the entire life cycle.

4.0 Bringing the Findings to Life

Below are six stories, representing four types of people (personae) and situations. Pseudonyms have been used, and each personae is based on the experiences of several different people. The quotes in each story are real and taken from more than one person.

For each story presented there are four subsections:

- Energy Survey and Interview Findings – outlines the story and the household, including current energy supply challenges.
- Decarbonisation Assessment – the decarbonisation framework is applied, highlighting possible constraints, and the appropriate decarbonisation options are outlined.
- Summary of Suggested retrofit – outlines the suggested retrofits for four scenarios modelled using Standard Assessment Procedures (SAP). These scenarios are:
    - Baseline house - The house has had no significant energy efficiency upgrades as part of routine maintenance.
    - House as is - The house has had significant energy efficiency upgrades that go beyond routine maintenance, for example heat pumps and renewables.
    - Partial retrofit to 2030 - Householder's view on energy efficiency retrofit measures that can be undertaken.
    - Full retrofit to 2030 - Best practice energy efficiency retrofit undertaken to ensure fuel poverty is alleviated and decarbonisation targets are achieved. .
- Estimated Return on Investment – the estimated return on investment (ROI) for the decarbonisation options and retrofits, where applicable.

4.1 Story 1: David and Alice

Rural farmhouse, no young children, off grid, national park, private rent

Figure 3: Indicative image representative of Story 1.

Table 2: A summary of the house details for Story 1.

House Details	
Building type	Detached
Construction age	pre 1919
Stock type	House
Location	Rural - isolated
Grid connection	Not connected to gas or electric grid
Energy source(s)	Diesel generator, bottled gas, wind turbine, solar PV, BESS
Property Fabric	Single glazing, poor insulation standards

In a nutshell

Motivation and willingness: Keen to decarbonise, mainly for financial reasons

Barriers and ability to decarbonise: Financial barriers; access to trained professionals; planning regulations; dependency on landlord.

4.1.1 Energy Survey and Interview Findings

David and Alice live in an old farmhouse in a national park, where Alice's family has been a tenant for generations. The farm is remote and exposed to the elements, with a woodland and a stream that provides water for the house. The farm uses a diesel generator twice a day to generate electricity, and a back boiler for heating, which is also used for cooking. They also have bottled gas for cooking which they use occasionally. In addition to the generator, they invested in a wind turbine and solar panels on the field, to maintain the look of the historic roof. Maintaining all these energy sources require a lot of attention and expertise; it is mostly David's job.

Living off-grid is time consuming, and depends on the weather: "*OK, this morning. The battery was at 43%. That means I can absorb, we can absorb from the solar plenty without me having to think what to do with the surplus. But if it was the other way round, I'd be rushing to do the washing. Would you see to occupy my life? to an inordinate degree".*

Since their trusted tradesman retired, they have approached some professionals, but few have the knowledge to maintain a system with multiple energy sources: "*even the solar power person that could do off grid - we rang loads of them and they all went: 'we don't do off grid, we don't do off grid'*". David ends up doing a lot of the repairs because he knows the system well and can diagnose the problem quickly.

Due to its location, an electricity connection is financially impractical, but the couple wish they could connect to the grid. The landlord is considering an oil boiler, which will be an improvement for heating but not for sustainability. The house is cold, but farmwork involves a lot of outdoors time, and they do not like to complain: "*We can all survive. We're not living in the Arctic. We're living in England, which doesn't get freezing, does it? I just think sometimes you've just got to toughen up, like good all Yorkshire. Come on*". Since their children left the house, they only use part of the house, but some parts of the house that are not rendered with breathable perlite become damp: they have to wipe damp off the walls.

The house has many windows and they would love to replace them, but this is very expensive, and even more so due to their location in a national park, where planning regulations require the replacement to be more expensive wooden, sash-style windows: *"the national park is a good national park, but we don't want to live in a museum".*

They are not eligible for grants as they are not on benefits and not the owners of the property. Agricultural grants are aimed at large dairies, not small farms like theirs. The current situation is expensive and hard to maintain, and they are worried that their older sons may not return to the family home to work on the farm.

The couple is interested in decarbonising and have done a lot within their limited agency as tenants in a national park. However, while they are sympathetic to the cause, their main motivation is financial, and not environmental sustainability.

4.1.2 Decarbonisation Assessment

The location of the household is greater than 2 km from the nearest connection point, and the property is not in proximity to other households, as such a new connection is cost-prohibitive and is therefore not considered feasible.

The couple have already employed significant renewable energy sources on site, as such the assessment focusses on the most beneficial approach to support the modifications already completed. In this case the electrical supply of the household is provided by the solar PVs, wind turbine and BESS. The electrical needs of the property are currently not met, and the electricity must be ‘topped up’ twice a day with the diesel generator. The deficit in electricity from the renewable sources is likely a sizing issue; the solar PV and wind turbine should supply a surplus of electricity; however, the BESS likely does not have sufficient capacity to retain the surplus and therefore cannot supply sufficient electricity during high demand periods. Increasing the capacity of the BESS could ensure the electrical demands of the property are met.

The least invasive, and likely most cost effective, option to meet the electrical needs of the property would be to replace the diesel supply with hydrotreated vegetable oil (HVO). HVO would offer a more sustainable heating supply for the household, with CO_2 reductions of up to 90%. A cost increase of 10-15% compared to diesel could be expected compared to the existing diesel supply.

The heating demands of the household are currently met with a solid fuel back burner, with a large inefficient hot water tank. For a two-person household it is estimated that a 5 kW capacity heat pump would be required to meet the heating needs of the household.

It is proposed that an air source heat pump (air to water) is installed to meet the heating demand of the household. Whilst a ground source heat pump has no visual impact on the property, the air source heat pump could be considerably cheaper. The overall cost of an air source heat pump is up to £14,000 [4], although the likely cost for a 5 kW air source heat pump is approximately £11,000 [5]. A ground source heat pump could be up to £49,000 dependent on the configuration required (horizontal or vertical installation) [6], although a 5 kW ground source heat pump could cost approximately £24,000 [7] with much of this cost attributed to the installation process.

A heat pump would require electrical energy supply, for a 5 kW air source heat pump this would be approximately 7800 kWh per year. The input supply to the heat pump may be met by the existing provisions, a minimum of a 6 kW solar PV array and a HAWT (35.5 m^2 swept area minimum) would provide the required input supply. The exact capacity of the current renewables system is unknown, if the system capacity is less than required, additional systems would need to be installed. Alternatively, the additional supply could be provided by the existing diesel generator, with significantly reduced use.

The area is not located in an AONB; however, it is subject to local planning regulations for any significant development. Similar planning applications for heat pumps have been approved by the local authority. Although approval is not guaranteed, this precedent suggests that similar heat pump installation applications could be approved. The property could be eligible for a grant via the UK Government ‘Boiler Upgrade Scheme’, for up to £7,500 [8]. However, as the couple are tenants, the scheme would only be available to the landlord, who could in turn pass down the cost reductions. Given that the couple are multi-generational tenants, this is still considered a viable option. It is recommended that a Microgeneration Certification Scheme (MCS) accredited installer is used, there are two MCS accredited installation companies within 25 km of the property. To ensure maximum efficiency for the system it is suggested that a number of retrofits are made, as outlined in Section 4.1.3.

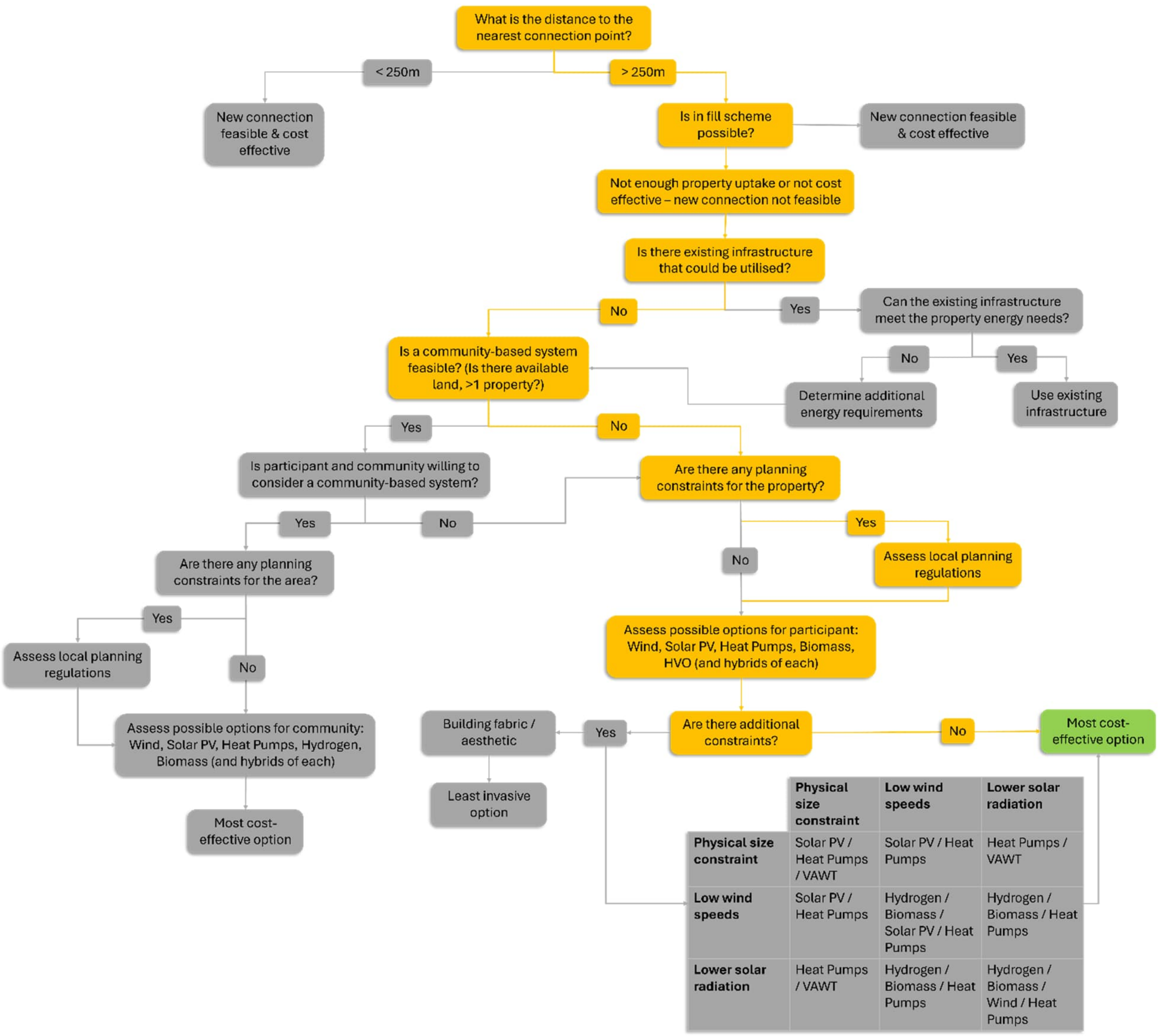

Figure 4: The decarbonisation assessment framework as applied to Story 1. Decisions made for Story 1 are highlighted in orange, the suggested decarbonisation option is highlighted in green.

Table 3: A summary of the suggested decarbonisation options for Story 1. Stated costs are capital costs and are indicative only.

Ranking	Description	Details	Possible Grants	Approximate Cost (£)	
				Without Grants	With Grants
1	HVO	• Requires fuel storage • Potential to reduce CO_2 emissions by up to 90%, but it is not an entirely 'clean' energy source • Supply could be affected by severe weather events • Can expect a 10-15% cost increase compared to the existing diesel supply	NA	-	NA
2	Air Source Heat Pump & BESS Capacity Increase	• Air to water heat pump (5 kW) • In conjunction with suggested retrofits to ensure maximum efficiency • Requires additional compatible hot water cylinder • If existing renewables are less than required supply, additional sources may be required • An increase in the BESS capacity would be required to supply the input energy demand of the heat pump	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'[2]	Approximately £11,000[3] (excluding additional BESS costs)	Approximately £3,500 (excluding additional BESS costs)

[2] The property is eligible for the Boiler Upgrade Scheme. As the couple are tenants, the scheme would only be available to the landlord, who could in turn pass down the cost reductions.

[3] Approximate cost for a 5 kW air to water heat pump is £11,000, but could cost up to £14,000. Cost is inclusive of a compatible hot water tank. Cost does not include maintenance, additional energy source for supply or extensive pipework retrofits.

Ranking	Description	Details	Possible Grants	Approximate Cost (£)	
				Without Grants	With Grants
3	Ground Source Heat Pump & BESS Capacity Increase	• In conjunction with suggested retrofits to ensure maximum efficiency • Requires additional compatible hot water cylinder • If existing renewables are less than required supply, additional sources may be required • An increase in the BESS capacity would be required to supply the input energy demand of the heat pump	Eligible for £7,500 grant under the 'Boiler Upgrade Scheme'[4]	Up to £24,000[5] (excluding additional BESS costs)	Approximately £16,500 (excluding additional BESS costs)
4	BESS Capacity Increase	• An increase in the BESS capacity could meet the electrical demands of the property • The installation and maintenance cost will be dependent on the BESS capacity required	NA	Unknown	

[4] The property is eligible for the Boiler Upgrade Scheme. As the couple are tenants, the scheme would only be available to the landlord, who could in turn pass down the cost reductions.

[5] The cost associated with a ground source heat pump can vary widely, depending on the specifics of installation at the property (i.e. vertical or horizontal installation etc).

4.1.3 Summary of Suggested Retrofit

Table 4: A summary of the suggested partial and full retrofits for Story 1.

Component:	Baseline	House As Is	Partial Retrofit to 2030	Full Retrofit to 2030
Walls	Limestone walls, problems with render	Limestone walls, problems with render	Limestone walls with 100mm internal insulation	Limestone walls with 100mm internal insulation
Roof	50mm insulation	300mm insulation	300mm insulation	400mm insulation
Floor	No upgrade	No upgrade	No upgrade	50mm over floor insulation
Window & Doors	Single glazing	Single glazing	Standard high performance (upvc)	Triple Glazing composite (timber)
Heating and Hot Water	Solid fuel back burner, with large inefficient hot water tank	Solid fuel back burner, with large inefficient hot water tank	Oil Combi boiler	Oil Combi boiler
Airtightness & Ventilation	Normal practice	Normal practice	Good practice	Good practice
Results				
SAP Rating	41	44	50	63
EPC Band	E	E	E	D
Fuel Bills	£2,425	£2,269	£2,030	£1,485
Decarbonised vs.1990		38%	62%	89%
Retrofit Costs			£23,000	£29,000
Disruption Factor			Very High	Very High

4.1.4 Estimated Return on Investment

Figure 5 shows the estimated ROI for an air source heat pump, ground source heat pump, partial and full retrofit installation for the property. The estimated annual fuel costs account for a 3% inflation each year. It is anticipated that the air source heat pump could reach ROI within 2 years, and the ground source heat pump could reach ROI within 6 years. Noting that this does not include the cost for the suggested BESS increase or maintenance. It is assumed that upon installation there would be no annual fuel cost for the property. It is anticipated that the full retrofit could reach ROI within 23 years, however the partial retrofit could take up to 28 years to reach ROI.

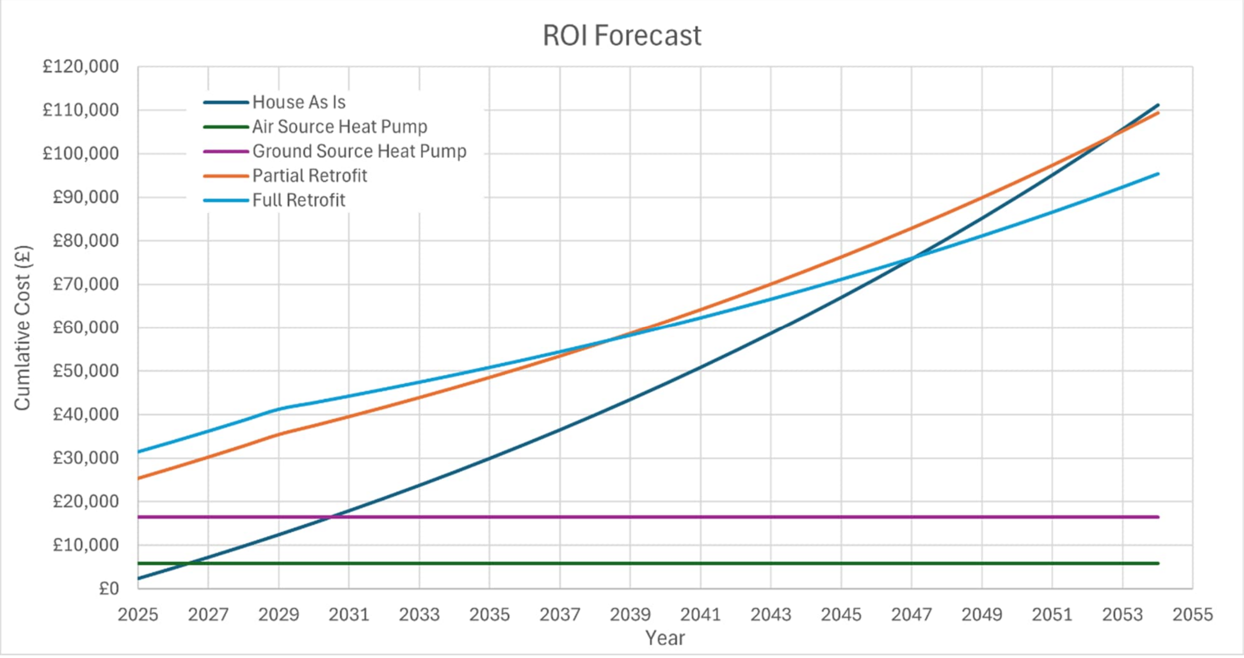

Figure 5: The forecasted ROI for an air source heat pump, ground source heat pump, partial and full retrofit installation for Story 1.

4.2 Story 2: Ben and Cath

Rural brick house, off gas, homeowners, retired environmentalist

Figure 6: Indicative image representative of Story 2.

Table 5: A summary of the house details for Story 2.

House details	
Building Type	Detached
Construction Age	Pre1960s
Stock type	Bungalow
Location	Village edge
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Solar PV, heat pump, BESS
Property Fabric	Double glazing, average insulation standard

In a nutshell

Motivation and willingness: Keen to decarbonise, especially for financial reasons

Barriers and ability to decarbonise: Access to trained professionals; planning regulations

4.2.1 Energy Survey and Interview Findings

Ben and Cath are retired environmental activists who own a detached brick house in a village off the gas grid. They both had professional jobs with a good income and also inherited some money, which they invested in comprehensive insulation, solar panels and a heat pump with underfloor heating. Their house is surrounded by trees that block the wind, but they are considering a vertical wind turbine to overcome this problem. They have a Tesla Powerwall to make the most of their solar energy. Their water is heated with a solar thermal system. They have an electric cooker with an energy efficient induction hob and an EV. Their main motivation is sustainability: "*we know that the actual cost of the electric is still probably higher than it would be if we had a gas boiler, but we do believe in the idea of approaching emissions free*".

They are very happy with their home. They live mindfully and manage their energy consumption carefully through calculated use of electricity when the solar panels generate power, setting the thermostat on a lower level and monitoring their consumption through a smart meter. They had to argue the case for solar panels on their roof, because the regulations in their protected areas required red roofs. They appealed and managed to install slate-looking solar panels. They still keep a log burner for cold evenings: it is their "guilty pleasure", as they are conscious of the negative impact of wood burning. *"it's a bit of, you know it's extra heat in the house. And it's also partly the aesthetic of it".* It is also, as Cath says, useful as a back-up for power cuts: *"because we are where we live, we are liable to power cuts because overhead cables, therefore having a secondary source of heating is useful".*

They have an EV, which they charge at home as there is no infrastructure for EV in the area. It is not only more sustainable but also more economical: 2p per mile. They argue that with good planning there is no reason for 'range anxiety': when going on long journeys, they plan their stops carefully in advance.

Ben and Cath are technologically savvy and keen to learn – they even took some courses – but they still find that some technologies are too complex for older people: a dial or button would be simpler than a set of electronic menus. Ben says that ironically, older people "*have the most resource to invest in these technologies but we have the least ability to make them work".* Finding tradesmen who know about high performing insulation and new technologies was a struggle: there was little advice available and very few tradesmen who had the expertise to do the job. Ben and Cath had to micro-manage the workers to make sure there are no gaps or drilling that compromises the wall insulation. "*I guess the other bit behind that is expert training. You know actually training up people and incentivising them to be trained".*

Money is also an issue. Although they could afford it and were willing to spend on sustainable solutions, they would like to see a better feed in tariff for solar energy, because at the moment the return on investment is low. They were not eligible for grants, and this meant that the work took a long time to complete, as they were slowly investing in new elements. They had to empty their home and rent a house for six months while work was in progress; it was disruptive.

Ben and Cath would love to see a community-based energy solution in their village, which is off the gas. But they think the chances are slim and are frustrated with their less environmentally-minded neighbours: one of them has just installed a new oil boiler, which Cath thinks is outrageous. This is partly due to lack of expert advice: their neighbour was advised that their property is not suitable for a heat pump, but "*they're going to be externally rendering it so they could have had external insulation without any problem at all".*

4.2.2 Decarbonisation Assessment

The location of the household is approximately 11.5 km from the nearest gas connection point. Whilst the property is in proximity to other households, the distance for a new connection is significant, and a new connection (including for an in-fill scheme) would be cost-prohibitive and is not considered feasible.

The couple have already employed significant renewable energy sources and storage systems on site, as such the assessment focusses on the most beneficial approach to support the modifications already completed.

A community-based energy solution could be considered for the village, there are approximately 40 houses within the area. As a minimum, the community-based scheme would require buy-in from the households within the area, sufficient land to site the required equipment, and planning permission from the local authorities. Screening for planning applications within the same local authority for multiple wind turbines showed that the majority of households would object to the siting of multiple wind turbines. A solar and BESS or hybrid community system could be possible, but would likely have high costs associated, and would likely not have community buy-in. As such, whilst the community scheme may be possible, it is not considered the most suitable option for this household.

Alternatively, a single small scale wind turbine could be considered for the property itself, this could be a vertical or horizontal axis turbine. Planning applications for single small scale turbines (≤ 18 m mast height) have been approved within the area. Although approval is not guaranteed, this precedent suggests that similar small scale wind turbine installation applications could be approved.

A VAWT could be mounted on the external walls or roof of the house. A single wall / roof mounted VAWT (2 kW) could provide up to 480 kWh per year and would require approximately 2.6 m^2 of area. Ideally, multiple wall / roof mounted VAWTs would be installed to provide sufficient electricity generation for the household, 5 wall / roof mounted VAWTs (2 kW) could provide up to 2400 kWh per year (the typical electric consumption for a 2-person household is 5700 kWh per year, inclusive of EV charging, the rest of the electric demand is assumed to be met by the solar PV array). However, this would be dependent on the local authority, spacing allowances for the wall / roof area of the property. It would likely cost up to £4000 to install a single VAWT [9].

Alternatively, standalone (ground mounted) VAWT (≤ 18 m mast height, 7.5 kW) could provide up to 4687 kWh per year and would require approximately 23 m^2 of area for siting. The annual energy production from a single standalone VAWT would likely be in excess of the household requirements, and there is potential for surplus electricity to be exported back to the grid [10]. Typical rates for exported electricity range from 20 to 40 p/kWh [11], as such an estimated £430 - £860 could be generated for the household annually. It could cost up to £55,000 to install a single standalone VAWT [12]. It is likely there is insufficient area available to install / maintain safety margins around a HAWT (≤ 18 m mast height).

It is recommended that the current BESS is updated to increase capacity if VAWTs are installed, to ensure maximum efficiency of the additional energy generation. For a single wall / roof mounted VAWT, additional BESS capacity may not be required. However, for 5 wall / roof mounted VAWTs, or a standalone VAWT, an additional 27 kW BESS capacity would be required as a minimum, this is the equivalent of 2 Tesla Powerwalls.

It is recommended that a MCS accredited installer is used to install any equipment. There is an MCS accredited standalone VAWT installation company within 35 km of the property, and there are multiple MCS accredited companies that install building mounted VAWT that cover this location. There are no UK Government grants available for small scale domestic wind turbines.

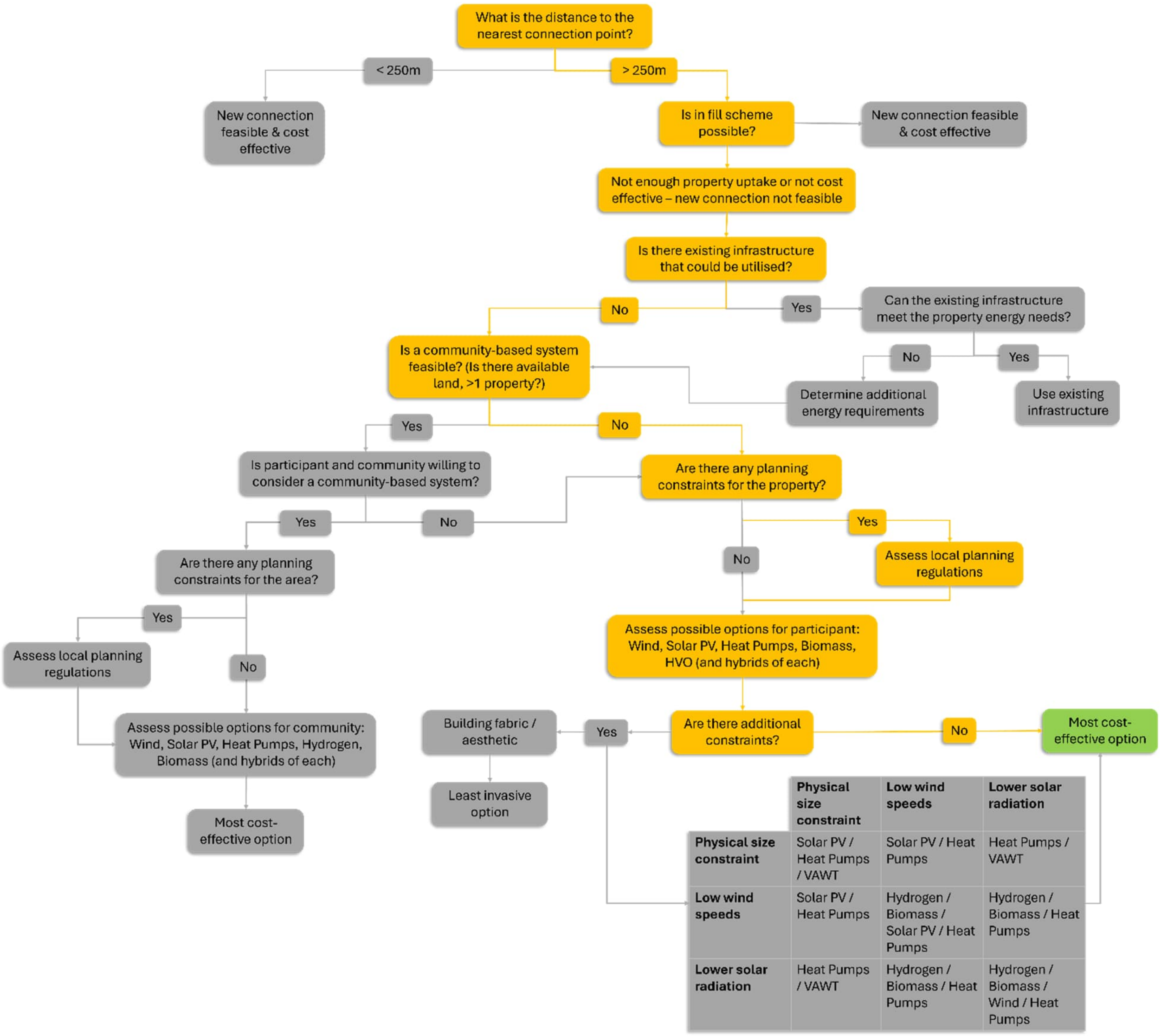

Figure 7: The decarbonisation assessment framework as applied to Story 2. Decisions made for Story 2 are highlighted in orange, the suggested decarbonisation option is highlighted in green.

Table 6: A summary of the suggested decarbonisation options for Story 2.

Ranking	Description	Details	Possible Grants	Approximate Cost (£)	
				Without Grants	With Grants
1	VAWT	• Single wall or roof mounted VAWT (2 kW) • This would require an approximate area of 2.6 m^2 available for siting • Note that this will not provide the full electrical requirement for the household	NA	Up to £4,000[6])	NA
2	VAWT	• 5 wall or roof mounted VAWT (2 kW) • Increase to 40.5 kW BESS capacity (3 Tesla Powerwalls total, inclusive of the existing Powerwall on the property) • This would require an approximate area of 16 m^2 available for siting • The installation would require approval from the local authority		Up to £32,000[7]	
3	VAWT	• Single standalone VAWT (18 m mast height, 7.5 kW) • Increase to 40.5 kW BESS capacity • This would require an approximate area of 26 m^2 available for siting • Potential for up to £430 - £860 generated per year • The installation would require approval from the local authority		Up to £66,000[7]	
4	Community Based Scheme	• 600 m^2 of solar PV (fixed axis, 0.2 MW array) • 4 mid-size HAWT (80 kW) • 400 kW BESS • This would require buy in from the community, and an approximate area of 2240 m^2 available for siting) • There would be significant maintenance costs associated with a site of this scale • Cost per household would likely be too high for the scheme to be viable		Up to £304,000 (£7,600 per household[77]	

[6] Not including associated maintenance cost.
[7] Approximate, assuming 40 households and an average electrical demand of 5700 kWh per household annually, accounting for future EV use. It is assumed that heating demands of the properties are met outside of this scheme. The installation of EV infrastructure (e.g. charging points) is not included within this cost.

Ranking	Description	Details	Possible Grants	Approximate Cost (£)	
				Without Grants	With Grants
5	Community Based Scheme	• 1250 m^2 of solar PV (fixed axis, 0.45 MW array)[8] • 200 kW BESS • This would require buy in from the community, and an approximate area of 1380 m^2 available for siting) • There would be significant maintenance costs associated with a site of this scale • Cost per household would likely be too high for the scheme to be viable.		Up to £645,000 (£16,125 per household[9])	
6	Community Based Scheme	• 6 mid-size HAWT (80 kW) • 400 kW BESS • This would require buy in from the community, and an approximate area of 2360 m^2 available for siting) • Note that this is unlikely to be approved by local planning authorities • Cost per household would likely be too high for the scheme to be viable		Up to £48,000 (£12,000 per household[10])	

[8] Note that during the transition period for this scheme, dependent on the season/solar irradiance, there is likely to be insufficient energy for the initial period.
[9] Approximate, assuming 40 households and an average electrical demand of 5700 kWh per household annually, accounting for future EV use. It is assumed that heating demands of the properties are met outside of this scheme. The installation of EV infrastructure (e.g. charging points) is not included within this cost.

4.2.3 Summary of Suggested Retrofit

Table 7: A summary of the suggested partial and full retrofits for Story 2.

Component:	Baseline	House As Is	Partial Retrofit to 2030	Full Retrofit to 2030
Walls	Brick cavity wall	Brick cavity wall with insulation	Brick cavity wall with insulation	Brick cavity wall with insulation
Roof	300mm insulation	300mm insulation	300mm insulation	400mm insulation
Floor	No upgrade	No upgrade	No upgrade	Floor insulation
Window & Doors	Double glazing	Double glazing	Standard high performance (upvc)	Triple Glazing composite (timber)
Heating and Hot Water	Oil boiler with hot water tank	Heat pump	Heat pump	Heat pump
Airtightness & Ventilation	Normal practice	Normal practice	Good practice	Good practice
Results				
SAP Rating	35	41	43	67
EPC Band	F	E	E	D
Fuel Bills	£1,935	£1,725	£1,658	£948
Decarbonised vs.1990		83%	84%	89%
Retrofit Costs			£16,000	£22,000
Disruption Factor			Medium	Very High

4.2.4 Estimated Return on Investment

Figure 8 shows the estimated ROI for five building mounted VAWT (2 kW) with BESS, a single standalone VAWT (18 m mast height, 7.5 kW) with BESS, a hybrid community scheme (solar, wind and BESS) and partial and full retrofit installations for the property. The estimated annual fuel costs account for a 3% inflation each year. It is anticipated that 5 building mounted VAWT (2 kW) with BESS could reach ROI within 19 years. A single standalone VAWT (18 m mast height, 7.5 kW) with BESS could reach ROI within 22 years, and generate up to £860 per year after ROI is achieved. The hybrid community based scheme could achieve ROI after 5 years, provided that all properties within the village partake in the scheme. Note that this does not include the cost for maintenance. It is assumed that upon installation there would be no annual fuel cost for the property.

It is anticipated that a full retrofit could reach ROI within 21 years, however the partial retrofit could take up to 36 years to achieve ROI.

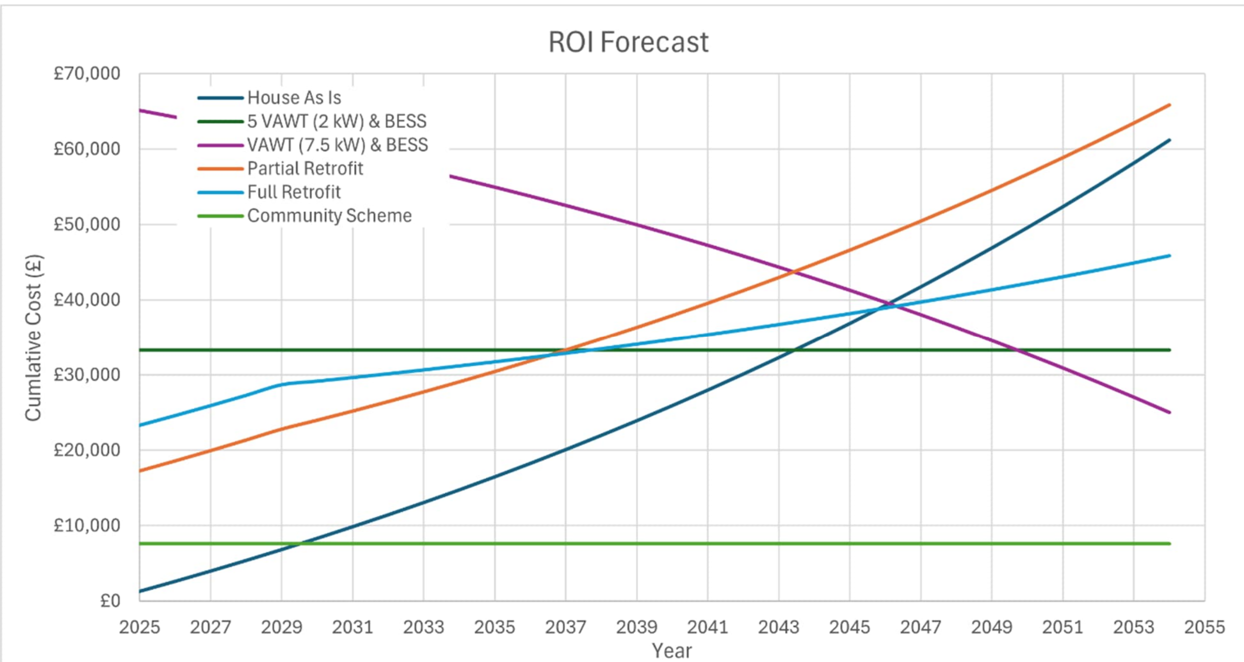

Figure 8: The forecasted ROI for five building mounted VAWT (2 kW) with BESS, a single standalone VAWT (18 m mast height, 7.5 kW) with BESS, a hybrid community scheme (solar, wind and BESS) and partial and full retrofit installations for Story 2.

4.3 Story 3: Heather

Rural flat, off gas, social rent, disability, fuel poverty

Figure 9: Indicative image representative of Story 3.

Table 8: A summary of the house details for Story 3.

House details	
Building Type	Semi-detached
Construction Age	Pre 1919
Stock type	Ground floor flat
Location	Village
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Ground source heat pump, solar PV
Property Fabric	Double glazing, average insulation standard

In a nutshell

Motivation and willingness: Keen to decarbonise for financial and environmental reasons

Barriers and ability to decarbonise: Dependency on landlord; financial; local infrastructure

4.3.1 Energy Survey and Interview Findings

Heather lives in a two-bed semi-detached social housing home. Her small town is not connected to gas and is prone to power cuts. Heather is disabled and needs to keep the house warm and have frequent warm baths to manage her condition. She relies on electricity to store her medication in the fridge. The frequent power-cuts in the area, especially during winter storms, are challenging. The house has double glazing and has recently been fitted with a ground source heat pump and solar panels. Heather is very calculated with her energy use, opting for a microwave and air fryer rather than using their electric cooker, which she only uses when she's hosting. She regularly uses hot water bottles and electric blankets and sets the thermostat on 17°C to save on electricity, despite its negative impact on her health.

The heat pump, together with the insulation and double glazing, made the house warmer and has helped Heather save on energy. The new system is simple to use and not very different from the oil boiler, but she sometimes misses the strong heat she enjoyed with the oil. Heather is also frustrated about the size of the new radiators: they are larger and take up a lot of space in the small bathroom. She was advised not to dry their clothes on the new radiators, which requires more space for a drying rack.

Heather wishes she could have batteries to store the solar energy – this could help store her medication and help save on electricity. It will also mean that the house will be almost self-sufficient and could be really off-grid if needs be, which Heather thinks is preferable for sustainability. Heather would be happy to change habits in order to reduce carbon emissions, but it is difficult without data on output electricity. Unfortunately, the housing association did not connect her solar panels to a smart meter, so she cannot feed it into the grid or see how much they generate. Ideally, she'd love to have access to an app on her phone or a visible display of her energy consumption.

Previously, the house had an oil boiler and electric heaters, which were too expensive to run with the rising electricity costs. Heather uses a car regularly – there are no supermarkets or a GP in the town, so she travels to the next town, spending on petrol more than she would have liked. An EV is not an option due to lack of infrastructure: there is no charging point near the house and none in the area. Heather spends a lot of time at home. She takes advantage of daylight to do the washing and cooking, so she can make the most of the free solar power.

4.3.2 Decarbonisation Assessment

The location of the household is greater than 2 km from the nearest gas connection point. Whilst the property is in proximity to other households, a heat pump has been installed for the property and meets the heat demand, as such a new connection is cost prohibitive.

There are already significant renewable energy sources on site, as such the assessment focusses on the most beneficial approach to support the modifications already completed. In this case the heating demanads of the household are met, although could be improved. The electrical generation need is met; however, the continuous supply of electricity (resilience) is a significant issue for the household. A BESS would ensure that the property receives continuous electricity.

The property is not located in an AONB; however, it is located close to a national park and is subject local planning regulations for any significant development. Similar planning applications for BESS have been approved by the local authority. Although approval is not guaranteed, this precedent suggests that BESS installation applications could be approved.

Based on the average energy requirements for a single occupancy flat (within a semidetached property), and the estimated solar production for the location based on a 3.5 kW array, it is suggested that a BESS with a minimum 10 kW is installed. The BESS would ensure resilience of the electric supply to the household, noting that if the BESS is installed in January there will likely be a transition period with minimal grid reliance. The BESS (10 kW) would require approximately 0.2 m^2 of area for siting and could cost approximately £5000 to £7500. Domestic BESS are currently exempt from VAT [13].

Due to physical size limitations and local authorities, other renewable energy sources are not considered viable for the property. However, a community-based scheme could be possible. There are approximately 50 properties within the area. As a minimum, the community-based scheme would require buy-in from the households within the area, sufficient land to site the required equipment, and planning permission from the local authorities. Planning applications for solar PV and BESS have been approved by the local authority, and some small scale HAWT have been approved by the local authority if below 18 m mast height. It should be noted that whilst there is precedent for small scale, single household applications, larger community schemes have not been constructed within this area as of yet.

A hybrid solar PV, HAWT and BESS scheme would likely provide sufficient energy for the community, whilst remaining the most cost-effective option. A 134 kW solar PV array, two 80 kW wind turbines and 800 kW BESS scheme would provide sufficient energy for the town. It is assumed that there are 50 households within the town, with an average electrical consumption of 5700 kWh per household annually, including future EV use. The cost for this hybrid scheme would be approximately £340,000 in total, and £6,800 per household, assuming all households within the town partake in the scheme. This is a capital cost only and is exclusive of anticipated maintenance costs.

Alternatively, a wind or solar only community-based scheme could be considered. A hybrid scheme could be more likely to be approved than a HAWT only community scheme. A solar PV only community scheme could provide the energy required for the town but would likely require a large site (up to 1500 m^2) and would require a greater BESS capacity to provide resilience for the town. An alternative to the BESS system would be to use a HESS system in conjunction with an on-site electrolyser, however this would require significant gas infrastructure, that the local area does not currently have, and as such would likely be cost prohibitive.

Figure 10: The decarbonisation assessment framework as applied to Story 3. Decisions made for Story 3 are highlighted in orange, the suggested decarbonisation option is highlighted in green.

Table 9: A summary of the suggested decarbonisation options for Story 3.

Ranking	Description	Details	Possible Grants	Approximate Cost (£)	
				Without Grants	With Grants
1	BESS	• BESS (10 kW) • This would require an approximate area of 0.2 m^2 available for siting (outdoor, garage and can be wall mounted)	NA	£5,000 to £7,500	NA
2	Community Based Scheme	• 750 m^2 of solar PV (fixed axis, 134 kW array) • 2 mid-size HAWT (80 kW) • 1.0 MW BESS • This would require buy in from the community, and an approximate area of 1625 m^2 available for siting) • There would be significant maintenance costs associated with a site of this scale	NA	Up to £340,000 (£6,800 per household[10][11])	NA
3	Community Based Scheme	• 1500 m^2 of solar PV (fixed axis, 0.27 MW array)[12] • 800 kW BESS • This would require buy in from the community, and an approximate area of 1660 m^2 available for siting) • There would be significant maintenance costs associated with a site of this scale	NA	Up to £560,000 (£11,200 per household[11][12])	NA
4	Community Based Scheme	• 4 mid-size HAWT (80 kW) • 1.2 MW BESS • This would require buy in from the community, and an approximate area of 1590 m^2 available for siting) • Note that this is unlikely to be approved by local planning authorities	NA	Up to £520,000 (£10,400 per household[11][12])	NA

[10] Approximate, assuming 50 households and an average electrical demand of 5700 kWh per household annually, and accounting for future EV use. It is assumed that heating demands of the properties are met outside of this scheme. EV infrastructure, for example charging points, are not included within this cost.

[11] Not including associated maintenance costs.

[12] Note that during the transition period for this scheme, dependent on the season/solar irradiance, there is likely to be insufficient energy for the initial period.

4.3.3 Summary of Suggested Retrofit

Table 10: A summary of the suggested partial and full retrofits for Story 3.

Component:	Baseline	House As Is	Partial Retrofit to 2030	Full Retrofit to 2030
Walls	Limestone walls	Limestone walls	Limestone walls with 100mm internal insulation	Limestone walls with 100mm internal insulation
Roof	300mm insulation	300mm insulation	300mm insulation	400mm inuslation
Floor	No upgrade	No upgrade	No upgrade	50mm over floor insulation
Window & Doors	Double glazing	Double glazing	Standard high performance (upvc)	Triple Glazing composite (timber)
Heating and Hot Water	Oil boiler hot water tank	Heat pump and tank	Heat pump and tank	Heat pump and tank
Airtightness & Ventilation	Normal practice	Good practice	Good practice	Good practice
Results				
SAP Rating	52	40	52	70
EPC Band	E	E	E	C
Fuel Bills	£774	£971	£778	£489
Decarbonised vs.1990		83%	86%	90%
Retrofit Costs			£15,000	£19,000
Disruption Factor			High	Very High

4.3.4 Estimated Return on Investment

Figure 11 shows the estimated ROI for a hybrid community scheme (solar, wind and BESS) and partial and full retrofit installations for the property. The estimated annual fuel costs account for a 3% inflation each year. The suggested BESS has not been included for the ROI forecast, as it will likely not affect the annual fuel cost but will provide resilience for the property.

It is anticipated that the community-based scheme could achieve ROI within 7 years, provided all properties within the town partake in the scheme. Note that this does not include the cost for maintenance. It is assumed that upon installation there would be no annual fuel cost for the property.

It is anticipated that a full retrofit could reach ROI within 25 years, however the partial retrofit could take up to 31 years to achieve ROI.

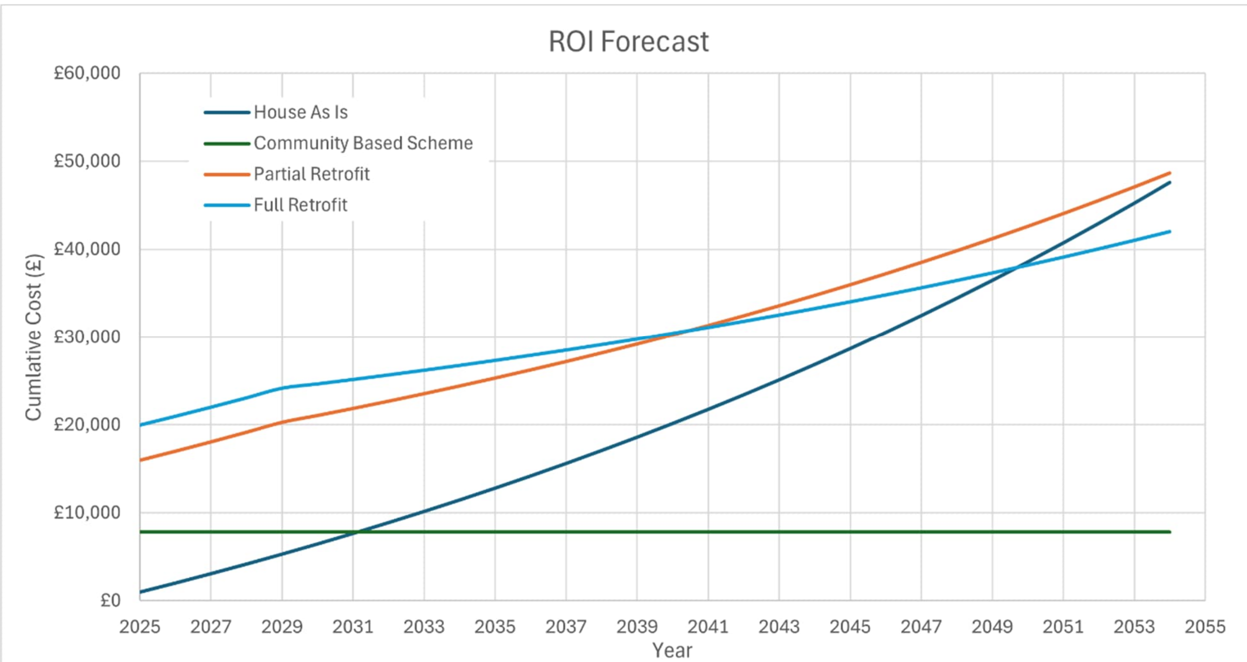

Figure 11: The forecasted ROI for a hybrid community scheme (solar, wind and BESS) and partial and full retrofit installations for Story 3.

4.4 Story 4: Katy and Dan +3

Urban semi, off gas, family, social rent, saving on heating

Figure 12: Indicative image representative of Story 4.

Table 11: A summary of the house details for Story 4.

House details	
Building Type	Semi-detached
Construction Age	1960s
Stock type	House
Location	Town
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Mains electric

In a nutshell

Motivation and willingness: Willing to decarbonise to save money

Barriers and ability to decarbonise: Financial; dependency on landlord; habits and preference for high temperatures

4.4.1 Energy Survey and Interview Findings

Katy and Dan live with their three children in a semi-detached house in a small town off the gas grid. Their house is cold and draughty despite attempts to insulate it and is not suitable for a heat pump. It is fitted with inefficient storage heaters that provide very little heat during the day and work during the night on low tariff, when they are in bed. By the time the children are back from school, the house is cold: "it's totally the wrong way round!". They use an electric fire in the sitting room and heaters in the kids' bedrooms, but not in the parents' bedroom.

The rising cost of electricity is a big issue: the heaters are on less, the hot water is on less, the cooker is on less, and consequently the house is colder and damper. "I'll be either freezing or have no money", says Katy. In the past, "electricity used to cost as much as rent". Now, with the electricity cap, they pay less. Katy and Dan take quick showers, but bathing the children is still costly. Katy likes to keep the house warm – in their previous house, the thermostat was set to 25°C, but they cannot afford it in this house. Dan thinks electricity should be cheaper than gas. Katy thinks that fitting solar panels on the house's large, South-facing roof is 'a no brainer', but the housing association has not done it.

While Dan would like a more energy efficient house, he also appreciates the character of the old house and feels that there is a trade-off he's willing to make between energy efficiency and living in a beautiful area in an old house. He would be reluctant to dig up his beautiful garden to fit a ground source heat pump, even if it was offered to them.

4.4.2 Decarbonisation Assessment

It should be noted that the heat demand for the property is also met by the mains electric, which is operated by NPG and is already transitioning towards 'clean' energy, as detailed in Section 3.1. As such the proposed options focus on the requirement to provide a more economical energy provision for the household.

The location of the household is approximately 11.5 km from the nearest gas connection point. Whilst the property is in proximity to other households the distance for a new connection is significant, and a new connection (including for an in-fill scheme) would be cost-prohibitive and as such is not feasible.

A community-based energy solution could be considered for the town, there are approximately 30 houses within the area. As a minimum, the community-based scheme would require buy-in from the households within the area, sufficient land to site the required equipment, and planning permission from the local authorities. Planning applications have been approved for solar PV, wind turbines and BESS within the area, this precedent suggests that similar applications could be approved, although approval is not guaranteed.

A hybrid solar PV, HAWT and BESS scheme would likely provide sufficient energy for the community, whilst remaining the most cost-effective option. A 350 kW solar PV array, three 80 kW wind turbines and 1.2 MW BESS scheme would provide sufficient energy for the town. It is assumed that the average heating and electrical energy consumption per household is 18400 kWh annually, including future EV use. The cost for this hybrid scheme would be approximately £907,000 in total, and £18,145 per household, assuming all households within the town partake in the scheme. This is a capital cost only and is exclusive of anticipated maintenance costs.

Alternatively, a wind or solar only community-based scheme could be considered. A hybrid scheme could be more likely to be approved than a HAWT only community scheme. A solar PV only community scheme could provide the energy required for the town but would likely require a large site (up to 1500 m^2) and would require a greater BESS capacity to provide resilience for the town. An alternative to the BESS system would be to use a HESS system in conjunction with an on-site electrolyser, however this would require significant gas infrastructure, that the local area does not currently have, and as such would likely be cost prohibitive.

Alternatively, the most cost-efficient option for the household, with minimal impact to the property aesthetic, would be to install an air source heat pump (air to water, 5 kW). The overall cost of an air source heat pump is up to £14,000 [4], although the likely cost for a 5 kW air source heat pump is approximately £11,000 [5]. The property could be eligible for a grant via the UK Government 'Boiler Upgrade Scheme', for up to £7,500 [8]. It is recommended that a MCS accredited installer is used, there is a MCS accredited installation company within 11 km of the property.

The electrical supply for the air source heat pump could be met by the mains electric grid, or alternatively by a solar PV (8.4 kW array) and BESS (10 kW) system. The solar PV and BESS system would require approximately 52 m^2 for siting, and cost approximately £14,000 in addition to the air source heat pump, this may not be feasible for the household.

Table 12: A summary of the suggested decarbonisation options for Story 4.

Ranking	Description	Details	Possible Grants	Approximate Cost (£)	
				Without Grants	With Grants
1	Community Based Scheme	• 2000 m² of solar PV (fixed axis, 350 kW array) • 3 mid-size HAWT (80 kW) • 1.2 MW BESS • This would require buy in from the community, and an approximate area of 3400 m² available for siting) • There would be significant maintenance costs associated with a site of this scale	NA	Up to £907,000 (£18,145 per household[13][14])	NA
2	Community Based Scheme	• 3000 m² of solar PV (fixed axis, 0.53 MW array) [15] • 600 kW BESS • This would require buy in from the community, and an approximate area of 3305 m² available for siting) • There would be significant maintenance costs associated with a site of this scale		Up to £820,000 (£16,400 per household[14] [15])	
3	Community Based Scheme	• 8 mid-size HAWT (80 kW) • 1.2 MW BESS • This would require buy in from the community, and an approximate area of 3155 m² available for siting) • Note that this is unlikely to be approved by local planning authorities		Up to £640,000 (£13,600 per household[14] [15])	

[13] Approximate, assuming 30 households and an average energy (electrical and heating) demand of 18400 kWh per household annually, and accounting for future EV use. EV infrastructure, for example charging points, are not included within this cost.

[14] Not including associated maintenance costs.

[15] Note that during the transition period for this scheme, dependent on the season/solar irradiance, there is likely to be insufficient energy for the initial start-up period.

Ranking	Description	Details	Possible Grants	Approximate Cost (£)	
				Without Grants	With Grants
4	Air Source Heat Pump	• Air source heat pump (air to water 5 kW), although this would be dependent on pipework compatibility • In conjunction with suggested retrofits to ensure maximum efficiency	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'[16]	Approximately £11,000[17] (excluding additional BESS costs)	Approximately £3,500 (excluding additional BESS costs)
5	Solar PV & Air Source Heat Pump & BESS	• Solar PV (8.4 kW array) • Air source heat pump (air to water 5 kW), although this would be dependent on pipework compatibility • BESS (10 kW) • In conjunction with suggested retrofits to ensure maximum efficiency	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'[17]	Up to £22,500	£15,000

[16] The property is eligible for the Boiler Upgrade Scheme. As the household are tenants, the scheme would only be available to the landlord, who could in turn pass down the cost reductions.

[17] Approximate cost for a 5 kW air to water heat pump is £11,000, but could cost up to £14,000. Cost is inclusive of a compatible hot water tank. Cost does not include maintenance, additional energy source for supply or extensive pipework retrofits.

4.4.3 Summary of Suggested Retrofit

Table 13: A summary of the suggested partial and full retrofits for Story 4.

Component:	Baseline	House As Is	Partial Retrofit to 2030	Full Retrofit to 2030
Walls	Brick cavity wall with insulation	Brick cavity wall with insulation	Brick cavity wall with insulation	Brick cavity wall with insulation
Roof	300mm insulation	300mm insulation	300mm insulation	400mm insulation
Floor	No upgrade	No upgrade	No upgrade	Floor insulation
Window & Doors	Double glazing	Double glazing	Standard high performance (upvc)	Triple Glazing composite (timber)
Heating and Hot Water	Storage heaters	Storage heaters	Heat pump	Heat pump
Airtightness & Ventilation	Normal practice	Normal practice	Good practice	Good practice
Results				
SAP Rating		17	58	71
EPC Band		G	D	C
Fuel Bills		£2,252	£1,005	£708
Decarbonised vs.1990		82%	91%	93%
Retrofit Costs			£15,000	£20,000
Disruption Factor			High	Very High

4.4.4 Estimated Return on Investment

Figure 11 shows the estimated ROI for a hybrid community scheme (solar, wind and BESS), a solar, air source heat pump and BESS system, and partial and full retrofit installations for the property. The estimated annual fuel costs account for a 3% inflation each year.

It is anticipated that the community-based scheme could achieve ROI within 7 years, provided all properties within the town partake in the scheme. The solar, air source heat pump and BESS system could achieve ROI within 5 years. Note that this does not include the cost for maintenance. It is assumed that upon installation there would be no annual fuel cost for the property.

It is anticipated that a full retrofit and partial retrofit could both achieve ROI within 13 years.

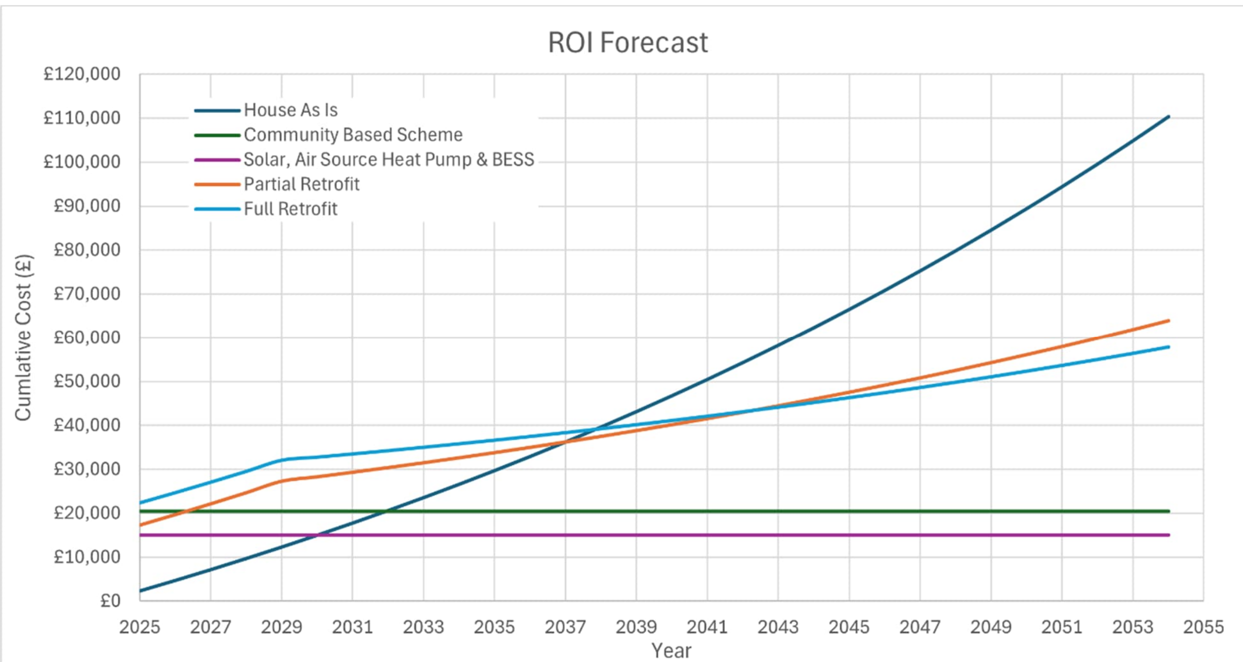

Figure 13: The forecasted ROI for a hybrid community scheme (solar, wind and BESS), a solar, air source heat pump and BESS system, and partial and full retrofit installations for Story 4.

4.5 Story 5: Catherine and Robert

Detached stone house, off gas, homeowners, retired older couple

Figure 14: Indicative image representative of Story 5.

Table 14: A summary of the house details for Story 5.

House details	
Building Type	Detached
Construction Age	Pre 1919
Stock type	House
Location	Rural
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Solar PV, oil, BESS
Property Fabric	Single glazing, average insulation standards

In a nutshell

Motivation and willingness: Willing to reduce carbon emission while balancing other needs such as habits, aesthetics and value for money.

Barriers and ability to decarbonise: Habit; planning; expert advice

4.5.1 Energy Survey and Interview Findings

Catherine and Robert have lived in their old, detached stone house for 50 years. Their village is off the gas grid. They have installed solar panels in the garden and have an EV. Their house is heated with an oil boiler that also keeps their beloved AGA working. They can afford the oil and are part of a local buying group "*which tries and negotiate a better price within the neighbourhood*". The main downside of the oil for them is the supply problems they faced during floods or bad weather. They found a balance they are happy with between sustainability, habit, and the character of the house.

Catherine and Robert love their house and are very attached to its aesthetics, including their sash windows, stone floor and mouldings: "*It's not just your energy needs, it's the combination of all our needs. And part of it is, is aesthetics",* says Robert. Catherine is appalled by the thought of future renovations to the house: *"somebody else coming into the house afresh, they rip out all windows. And they put in double glazing or triple glazing. That would be hideous (…). Somebody else might say, well, what we'll do is we'll insulate the inside of the walls whereupon all the mouldings will go".*

The solar panels are a welcome addition, but they require a lot of attention. While previously they took their electricity supply for granted, now "*it's a full-time occupation. If I weren't retired, I couldn't possibly do it*". By picking the right time to use electricity, Catherine can use the washing machine without worrying about *"what degree I'm running it at".* In summer, excess electricity feeds into the grid for low feeding tariff, making it unattractive to add more solar panels. Robert added that planners, being "*typically unhelpful*", were not keen on more than 14 panels anyway.

The couple were considering a thermal water heating system, but when they learnt that installing it would cost between £4,000-6,000 but will only save £76 per year, they decided it was a very low return on investment and does not add value to the house. Robert thinks it is something "*nobody in their right mind*" would do. Catherine would rather leave the major changes to the next generation: "*we always say, if our house goes to our children, they're going to have to work out what to do, because obviously, this is the end of an era. And it's just that at our age, if we invest now, we will never even see any benefit. We only have the outputs*".

Lack of professionalism is also at the root of their refusal to insulate their home; Catherine "*wouldn't let anybody come near my house with the barge pole*". A trusted builder told them about stone homes that became 'inhabitable' with damp after bad insulation jobs that were not sympathetic to the unique needs of old houses: "*unfortunately, a lot of (…) the people who are enrolled by, enlisted by the government to carry out these works, don't have that sort of skill*".

Robert is exasperated with tradespeople's lack of expertise and knowledge about new technologies. The car dealer "*didn't have a clue*" about technical aspects of the electric car; NPG could not provide data on voltage issues that was easily available via their Tesla Powerwall; their plumber suggested an efficient new boiler but a second opinion suggested that their old pipes were too narrow for this new technology: "*so the problem is the infrastructure, negotiating what was already there, which gets in the way even of new technology*". This also happened when the couple installed their solar panels and inquired about adding a wind turbine: "*the man looked us at us as if we were mad",* arguing that the two system were incompatible with each other. It is frustrating that professionals cannot offer consistent, reliable advice. Robert is equally suspicious of public information services, which he thinks range from impractical to nonsensical. His motto is: '*trust no one*'.

Catherine has concerns about heat pumps. Their neighbour has an old model that requires heating on cold days, which "*must cost a fortune*" to run if the pump needs heating at peak rate. Catherine also heard that the pipes' lifespan is only eight years, which they both don't think is sustainable or reasonable. They are very reluctant to dig up their beautiful stone floor or leave the house for an extended amount of time to allow for this – they are too old for that.

The couple took advantage of some financial incentives, but feel that the eligibility criteria are unfair: Their *'idle'* neighbours who rely on benefits were eligible for a free heat pump and other energy efficient support, while Robert, who has 'worked all his life and saved for a pension' cannot access this support. Catherine thinks the government should also support people like them. Speaking of the government, the couple felt that policy does not reflect the unique needs of the countryside. Catherine said: *"what I am conscious of is the government is thinking about forcing us into not using all the things that work for us, which they'll eventually will make this place, if that is forced upon somebody in this situation, they would have to shut the door and leave the house, probably".*

4.5.2 Decarbonisation Assessment

The location of the household is greater than 2 km from the nearest connection point, and the property is not in proximity to other households, as such a new connection is cost-prohibitive and is therefore not feasible.

As the property is isolated, a community-based scheme has not been considered for this household.

The couple have already employed renewable energy sources and storage on site, as such, the assessment focusses on the most beneficial approach to support the modifications already completed. In this case the electrical supply of the household is provided by the solar PVs and BESS. The electrical needs of the property are currently met by the renewable systems; however, the heating demand of the property are met with an oil boiler.

The property is not located in an AONB; however, it is located close to a national park and is subject local planning regulations for any significant development.

The building aesthetic is of great importance to the couple, and they are reluctant to change, as such the least invasive options should be considered. This includes a number of retrofits, as outlined in Section 4.5.3, to ensure maximum efficiency of the current system.

The least invasive option would be to replace the oil supply with hydrotreated vegetable oil (HVO). HVO would offer a more sustainable heating supply for the household, with CO_2 reductions of up to 90%. A cost increase of 10-15% compared to oil could be expected, and similar to oil there is likely to be supply issues during sever weather events.

It is suggested that the oil boiler is replaced with a biomass burner (minimum 30 kW). A biomass boiler could cost up to £20,000 [14], not including fuel costs. The fuel cost is likely to be £50-250 per tonne [14], resulting in an estimated annual fuel cost of up to £575. A biomass boiler would reduce the carbon footprint in comparison to the oil boiler, but it is not an entirely 'clean' energy source, as CO_2 is still produced. If the biomass fuel is obtained from a sustainably managed source, the CO_2 released during fuel consumption, should be matched by the CO_2 absorbed during the fuel growth The biomass boiler would require area for fuel storage, although this is likely to be similar to the existing storage requirements for the oil boiler. A biomass boiler requires a maintenance check once a year at a minimum and must be swept regularly.

A biogas burner could be considered, however, there are likely to be local supply issues to the area.

Alternatively, a heat pump could be installed, however this would be dependent on the existing pipework of the house. If the existing pipework is compatible with a heat pump, this could be a viable option, however if the pipework is not compatible, significant modifications to the house would be required, which the couple are reluctant to perform.

Whilst a ground source heat pump has no visual impact on the property, the air source heat pump could be considerably cheaper. The overall cost of an air source heat pump is up to £14,000 [4], although the likely cost for a 5 kW air source heat pump is approximately £11,000 [5]. A ground source heat pump could be up to £49,000 dependent on the configuration required (horizontal or vertical installation) [6], although a 5 kW ground source heat pump could cost approximately £24,000 [7] with much of this cost attributed to the installation process.

A heat pump would require electrical energy supply, which would likely not be met by the existing solar PV. As such the heat pump would likely require an additional electric source, which could be provided by the mains electric connection, or additional renewable sources.

The area is not located in an AONB; however, it is located within a national park and subject local planning regulations for any significant development. Similar planning applications for biofuel burners and heat pumps have been approved by the local authority. Although approval is not guaranteed, this precedent suggests that similar installation applications could be approved.

The property could be eligible for a grant via the UK Government 'Boiler Upgrade Scheme', for up to £7,500 for a heat pump and £5000 for a biomass boiler [8]. It is recommended that a MCS accredited installer is used, there are 2 MCS accredited installation companies within 40 km of the property.

It is acknowledged that the couple's 'beloved aga' would not be compatible with a biofuel burner or heat pumps. However, if the couple were willing, the oil powered aga could be replaced with an electric powered aga, which could be powered by either the biofuel or the existing solar panels.

	Physical size constraint	Low wind speeds	Lower solar radiation
Physical size constraint	Solar PV / Heat Pumps / VAWT	Solar PV / Heat Pumps	Heat Pumps / VAWT
Low wind speeds	Solar PV / Heat Pumps	Hydrogen / Biomass / Solar PV / Heat Pumps	Hydrogen / Biomass / Heat Pumps
Lower solar radiation	Heat Pumps / VAWT	Hydrogen / Biomass / Heat Pumps	Hydrogen / Biomass / Wind / Heat Pumps

Figure 15: The decarbonisation assessment framework as applied to Story 5. Decisions made for Story 5 are highlighted in orange, the suggested decarbonisation option is highlighted in green.

Table 15: A summary of the suggested decarbonisation options for Story 5.

Ranking	Description	Details	Possible Grants	Approximate Cost (£)	
				Without Grants	With Grants
1	HVO	• Requires fuel storage • Potential to reduce CO_2 emissions by up to 90%, but it is not an entirely 'clean' energy source • Supply could be affected by severe weather events • Can expect a 10-15% cost increase compared to the existing oil	NA	-	NA
2	Biomass Boiler	• Requires fuel storage • Not an entirely 'clean' energy source, but potential to be CO_2 neutral, depending on fuel sourcing • Estimated annual fuel cost of up to £575	Eligible for £5000 grant under the 'Boiler Upgrade Scheme'	Up to £20,000[18]	Approximately £15,000
3	Air Source Heat Pump	• In conjunction with suggested retrofits to ensure maximum efficiency • Dependent on pipework compatibility • Would likely require an additional electric source, which could be provided by the mains electric connection, or additional renewable sources	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'	Approximately £11,000[19]	Approximately £3,500
4	Ground Source Heat Pump	• In conjunction with suggested retrofits to ensure maximum efficiency • Dependent on pipework compatibility • Would likely require an additional electric source, which could be provided by the mains electric connection, or additional renewable sources	Eligible for £7,500 grant under the 'Boiler Upgrade Scheme'	Up to £24,000[20]	Approximately £16,500

[18] Approximate installation cost only. Annual fuel and maintenance cost is not included.

[19] Approximate cost for a 5 kW air to water heat pump is £11,000, but could cost up to £14,000. Cost is inclusive of a compatible hot water tank. Cost does not include maintenance, additional energy source for supply or extensive pipework retrofits.

[20] The cost associated with a ground source heat pump can vary widely, depending on the specifics of installation at the property (i.e. vertical or horizontal installation etc).

4.5.3 Summary of Suggested Retrofit

Table 16: A summary of the suggested partial and full retrofits for Story 5.

Component:	Baseline	House As Is	Anticipated Retrofit to 2030	Decarbonisation Retrofit to 2030
Walls	Limestone walls	Limestone walls	Limestone walls with 100mm internal insulation	Limestone walls with 100mm internal insulation
Roof	300mm insulation	300mm insulation	300mm insulation	400mm insulation
Floor	No upgrade	No upgrade	No upgrade	50mm over floor insulation
Window & Doors	Single glazing	Single glazing	Standard high performance (upvc)	Triple Glazing composite (timber)
Heating and Hot Water	Solid fuel back burner, with large inefficient hot water tank	Oil Combi boiler	Oil Combi boiler	Heat pump and tank
Airtightness & Ventilation	Normal practice	Normal practice	Good practice	Good practice
Results				
SAP Rating	53	45	60	76
EPC Band	E	E	D	C
Fuel Bills	£1,654	£1,949	£1,412	£832
Decarbonised vs.1990		48%	63%	93%
Retrofit Costs			£23,000	£35,000
Disruption Factor			Very High	Very High

4.5.4 Estimated Return on Investment

Figure 16 shows the estimated ROI for a biomass boiler, air source heat pump, ground source heat pump, and partial and full retrofit installations for the property. The estimated annual fuel costs account for a 3% inflation each year.

It is anticipated that the biomass boiler, air source heat pump and ground source heat pump could achieve ROI within 17, 2 and 13 years respectively. Note that this does not include the cost for maintenance. It is assumed that upon installation there would be no annual fuel cost for the property.

It is anticipated that a full retrofit could reach ROI within 23 years, and the partial retrofit could achieve ROI within 25 years.

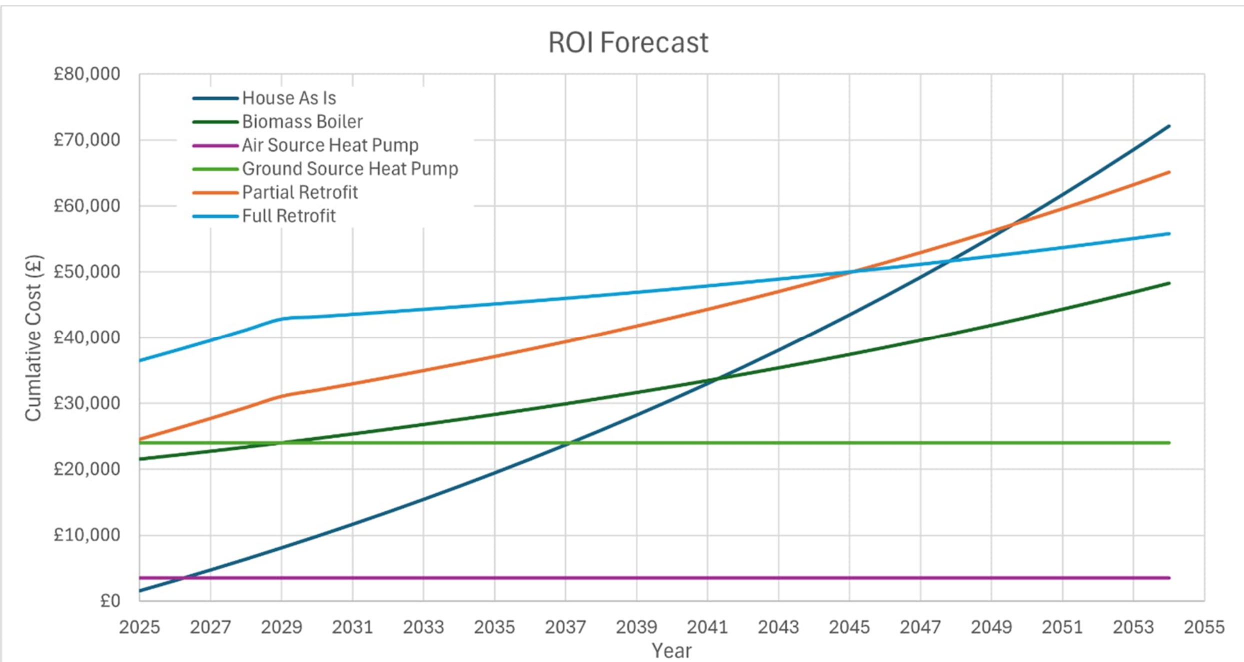

Figure 16: The forecasted ROI for a biomass boiler, air source heat pump, ground source heat pump, and partial and full retrofit installations for Story 5.

4.6 Story 6: Martin and Judith

Old detached house, oil boiler, homeowners, couple with one child

Figure 17: Indicative image representative of Story 6.

Table 17: A summary of the house details for Story 6.

House details	
Building Type	Detached
Construction Age	Pre 1919
Stock type	House
Location	Village
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Oil, mains electric
Property Fabric	Single glazing, poor insulation standards

In a nutshell:

Motivation and willingness: There is a willingness and a desire to improve the energy efficiency of the house, mainly for financial reasons and for warmth.

Barriers and ability to decarbonise: Financial barriers, as well as reluctance to engage in disruptive renovations.

4.6.1 Energy Survey and Interview Findings

Martin and Judith live with their teenage son in an old detached 3-bedroom house in a village that is off the gas grid. They have an oil boiler for water and heat, that heats up the ground floor. In the living room they have a wood and anthracite burner, which they only use in the evening because it requires too much work and attention. Judith says that the heating system is *"not fit for purpose"*, as it does not heat the whole house. Upstairs is heated with electric heaters: an electric heater in their son's bedroom and an immersion heater in theirs. The house is cold and draughty and poorly insulated, although they did some partial insulation in the loft. Martin works from home, so he uses an electric heater in his study during the day. He tries to use it sparingly, using a hot water bottle and blankets as well.

In the evenings, Judith and Martin sit in the living room by the fire, which Judith feels is "*quite essential, because it is used as secondary heat. How much could I have the central heating running all the time? and I don't think the house would still feel warm enough. And it also cuts down having to use that as well*". Their son spends more time in his room with the electric heater on.

Martin was looking into a dual action heat pump with oil top-up. Martin would ideally want to "*get rid of the oil"* and limit their use of the wood burner, because they are too expensive to run, especially considering the large upfront payment for 500L oil, which is the minimum. Overall, these costs and the rising costs of electricity make it very expensive to run the house. Judith, however, is "*very reluctant to get away from the oil*": "*you kind of have this concept of oil is better than electric when you live in like very rural areas" (…) "It's just you stick with what you know and you're very reluctant to move away from what you know and what you kind of rely on. And you know that it works to go to something new that you haven't got any guarantee. Is it going to be any better?"*

The family tries to limit their electricity use, for example by saving on heating water and avoiding using the electric cooker where possible, preferring the air fryer and microwave instead. They use hot water bottles and blankets in the evening, and the parents take hot water bottles to bed, while their son uses an electric blanket.

The couple were told that the house in its current state is not suitable for an air source heat pump, and their garden is too small for a ground source heat pump. They are not eligible for grants as they are not on benefits, however their income is not high enough to afford the necessary upgrades. They are concerned about the disruption and effort involved in potentially leaving the house, working at home while work is in progress, and having to redecorate after the work is done.

The couple would love to make changes to the house. Ideally, they will invest in insulation and possibly replace their draughty windows, although this might be difficult in terms of aesthetics, costs and planning. Their neighbour kept their sash windows because local planners declined their application for double glazed windows. Judith is wary of the bureaucratic burden of persuading planners of the need to make changes to the house. They think a wind turbine will not be suitable for their home for planning reasons but also due to the size of the garden and the potential noise. They were also looking at installing solar panels and a solar water heating system, but haven't made a decision yet, partly due to costs and slow return on investment, and partly because of the effort involved.

4.6.2 Decarbonisation Assessment

The household is connected to the electric grid, operated by NPG and already transitioning towards ‘clean’ energy, as detailed in Section 3.1. The primary concern for the household is economical and efficient heating, as such only the heating requirements of the property are considered for the decarbonisation assessment.

The location of the household is greater than 250 m from the nearest connection point, as such a singular new gas connection for the property is not considered viable. However, there a number of off-grid properties within the area, if the 30% property uptake criteria can be met, the in-fill scheme is considered to be a viable option. It is estimated that there are 40 properties within the area and would require approximately 12 properties to partake in the in-fill scheme. Following discussion with NGN it is estimated that the cost of the in-fill scheme would be £1,400,000. If all properties for the location were to partake in the in-fill scheme the cost would be £35,000 per household. It is noted that this is not the cheapest option, but would provide a continuous supply of heating, with minimal disruption to the households.

On an individual basis, the least invasive option would be to replace the oil supply with HVO. HVO would offer a more sustainable heating supply for the household, with CO_2 reductions of up to 90%. A cost increase of 10-15% compared to oil could be expected.

Alternatively, it is suggested that the oil boiler could be replaced with a biomass burner (minimum 30 kW). A biomass boiler could cost up to £20,000 [14], not including fuel costs. The fuel cost is likely to be £50-250 per tonne [14], resulting an estimated annual fuel cost of up to £575. A biomass boiler would reduce the carbon footprint in comparison to the oil boiler, but it is not an entirely ‘clean’ energy source, as CO_2 is still produced. If the biomass fuel is obtained from a sustainably managed source, the CO_2 released during fuel consumption, should be matched by the CO_2 absorbed during the fuel growth The biomass boiler would require area for fuel storage, although this is likely to be similar to the existing storage requirements for the oil boiler. A biomass boiler requires a maintenance check once a year at a minimum and must be swept regularly.

A solar thermal system could be a viable option for the couple, it is estimated that a 3.6 kW solar array in combination with a 150 L water heater would be sufficient for the household. The solar thermal system would cost approximately £30,500.

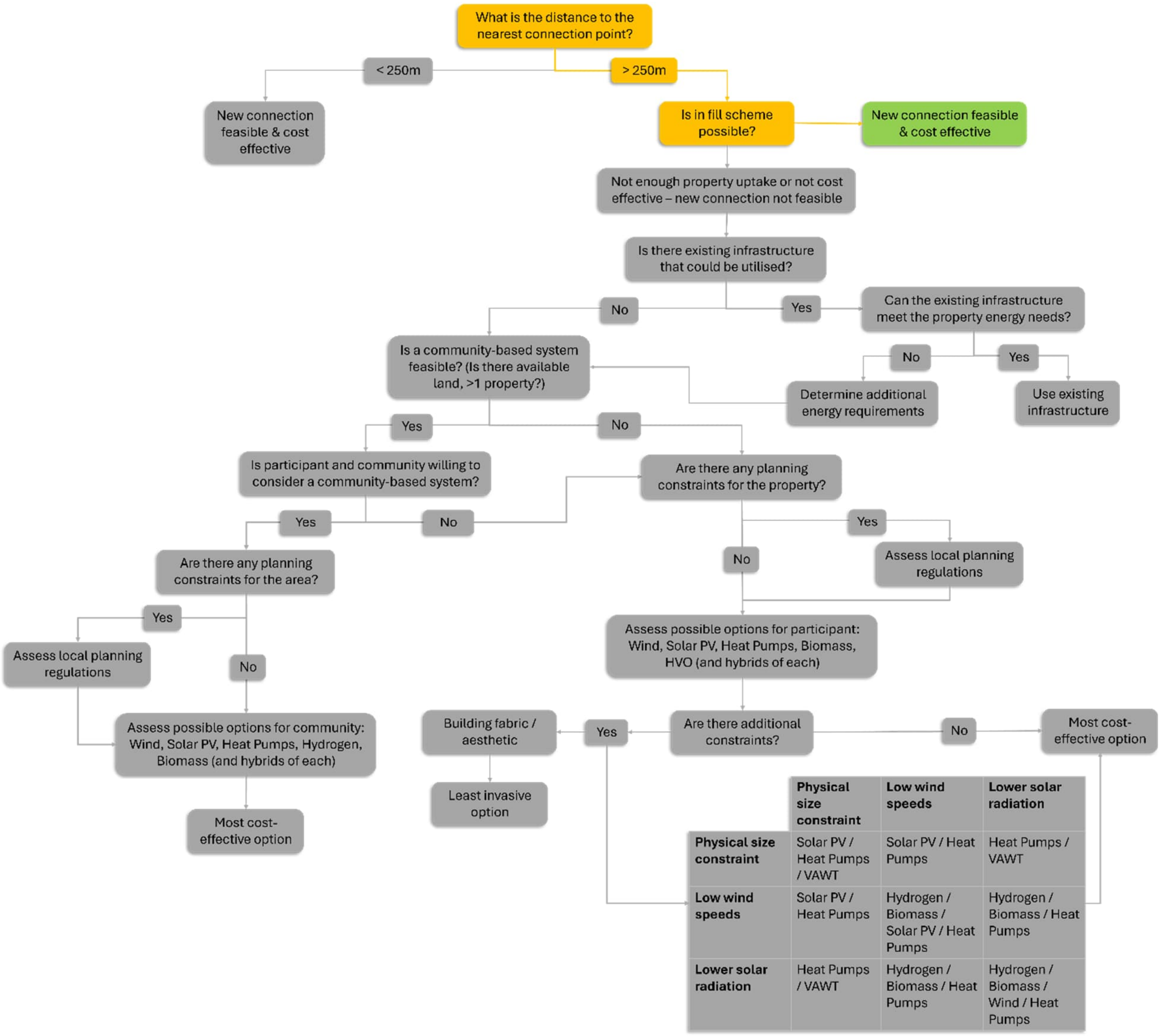

Figure 18: The decarbonisation assessment framework as applied to Story 6. Decisions made for Story 6 are highlighted in orange, the suggested decarbonisation option is highlighted in green.

Table 18: A summary of the suggested decarbonisation options for Story 6.

<table>
<tr><th rowspan="2">Ranking</th><th rowspan="2">Description</th><th rowspan="2">Details</th><th rowspan="2">Possible Grants</th><th colspan="2">Approximate Cost (£)</th></tr>
<tr><th>Without Grants</th><th>With Grants</th></tr>
<tr><td>1</td><td>New Gas Connection</td><td>• Provided that a property uptake of 30% is met (estimated to be 9 – 12 properties)
• Not a ‘clean’ energy, but will provide sufficient heating</td><td rowspan="2">NA</td><td>Up to £1,400,000 (£35,000 per household[21])</td><td rowspan="2">NA</td></tr>
<tr><td>2</td><td>HVO</td><td>• Requires fuel storage
• Potential to reduce CO_2 emissions by up to 90%, but it is not an entirely ‘clean’ energy source
• Supply could be affected by severe weather events
• Can expect a 10-15% cost increase compared to the existing oil</td><td>-</td></tr>
<tr><td>3</td><td>Biomass Boiler</td><td>• Requires fuel storage
• Not an entirely ‘clean’ energy source, but potential to be CO_2 neutral, depending on fuel sourcing
• Estimated annual fuel cost of up to £575</td><td>Eligible for £5000 grant under the ‘Boiler Upgrade Scheme’</td><td>Up to £20,000[22]</td><td>Approximately £15,000</td></tr>
<tr><td>4</td><td>Solar PV Heating System</td><td>• Would require installation of an immersion heater
• 3.5 kW solar PV array
• To ensure continuous heating and hot water supply a BESS (14 kW) system would be required</td><td>NA</td><td>Up to £30,500</td><td>NA</td></tr>
</table>

[21] Cost based on all households in the village partaking in the scheme. Cost based on a maximum of 6.4 km distance to nearest connection.
[22] Approximate installation cost only. Annual fuel and maintenance cost is not included.

4.6.3 Summary of Suggested Retrofit

Table 19: A summary of the suggested partial and full retrofits for Story 6.

Component:	Baseline	House As Is	Partial Retrofit to 2030	Full Retrofit to 2030
Walls	Limestone walls	Limestone walls	Limestone walls with 100mm internal insulation	Limestone walls with 100mm internal insulation
Roof	300mm insulation	300mm insulation	300mm insulation	400mm insulation
Floor	No upgrade	No upgrade	No upgrade	50mm over floor insulation
Window & Doors	Single glazing	Single glazing	Standard high performance (upvc)	Triple Glazing composite (timber)
Heating and Hot Water	Oil boiler	Oil boiler	Oil Combi boiler	Heat pump and tank
Airtightness & Ventilation	Normal practice	Normal practice	Good practice	Good practice
Results				
SAP Rating		44	60	75
EPC Band		E	D	C
Fuel Bills		£1,643	£1,157	£727
Decarbonised vs.1990		24%	47%	90%
Retrofit Costs			£18,000	£27,000
Disruption Factor			High	Very High

4.6.4 Estimated Return on Investment

Figure 19 shows the estimated ROI for a biomass boiler, solar heating system, and partial and full retrofit installations for the property. The estimated annual fuel costs account for a 3% inflation each year.

It is anticipated that the biomass boiler, and solar heating system could achieve ROI within 3 and 13 years respectively. Note that this does not include the cost for maintenance. It is assumed that upon installation there would be no annual fuel cost for the property.

It is anticipated that a full retrofit could reach ROI within 21 years, and the partial retrofit could achieve ROI within 22 years.

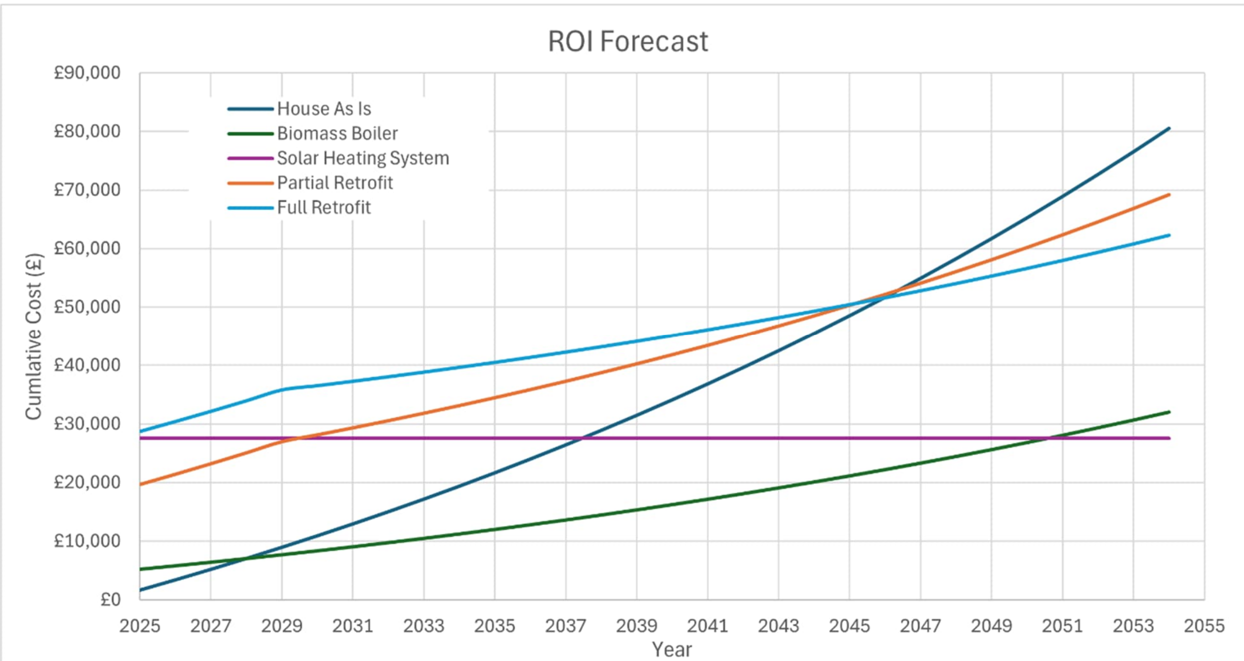

Figure 19: The forecasted ROI for a biomass boiler, solar heating system, and partial and full retrofit installations for Story 6.

5.0 Participant Feedback

The decarbonisation options were presented to a number of interview participants for their consideration and feedback. This was achieved through two separate focus groups conducted during January and February 2025: one was held online and included five participants from four households living in Cumbria and the Yorkshire Dales. The second was held in person in Pegswood, Northumberland and included two participants and two professional stakeholders working- directly with off grid households. We presented four of the case studies featured in the last chapter at each focus group, selecting examples relevant to the group and their circumstances. Overall, participants supported the various decarbonisation options we had identified for homes like theirs but suggested some minor adjustments including options that we had overlooked (i.e. secondary glazing, modern storage heaters). They also tended to support the more moderate scenarios, rather than the comprehensive decarbonisation packages, mainly on cost grounds. We also noted that:

- Occupants are more likely to improve the efficiency of the house with the suggested retrofits (either partial or full retrofits) prior to implementing the decarbonisation options.

- Space requirements and aesthetic impacts of specific technologies, for instance biomass boilers or ground source heat pumps, were a significant concern for households. Notably, it was for aesthetic reasons that many households had avoided double glazing. This includes any cosmetic changes or disruption caused by retrofits or decarbonisation options. For example: installation of internal wall insulation and / or the replacement of pipework and radiators necessary for heat pumps.

- Participants can be reluctant to pursue significant change and wish to hold on to technologies that they are familiar with, even when pursuing new technologies (for example: they may wish to retain a log burner as a backup or for enjoyment after installing a heat pump). This is a common preference, known as ‘heat stacking’

- The specifications for some technologies may need to have increased energy supply and storage capacity due to the current inefficiency of the home, increasing costs for occupants and reducing feasibility.

- Participants are often willing to consider community schemes, but for these to be feasible, there must be a collective voice from the community (spokesperson or similar).

    - Participants feel that more generous funding or grant schemes with fewer eligibility criteria would likely increase uptake in such schemes.

- Decarbonisation options are particularly challenging for households that rent their homes privately, not least because they must convince their landlord to make changes, and they may, in turn, pass the cost own to tenants through rent increases.

    - Often tenants would need a multi-generational tenancy to achieve ROI, and benefits might be seen by future generation rather than the current generation.

6.0 Conclusions and Recommendations

The research and decarbonisation assessment identified a number of common findings:

- Occupants are more likely to improve the efficiency of the house with the suggested retrofits (either partial or full retrofits) prior to implementing the decarbonisation options

- The majority of households that are not currently connected to the gas grid, have little desire to connect to it. Most are, however, eager to secure a reliable electricity supply, whether this is through a grid connection or other reliable source. In many cases the distance from the property to the nearest grid connection point renders a new connection cost-prohibitive and unfeasible.
    - For those households that have challenges with continuous energy supply (i.e. have frequent interruptions to supply) grid independence can be a desirable option as it would provide much needed resilience for the household.

- There is a drive towards the electrification of assets; as fuel prices continue to be volatile and there is a further drive for carbon neutrality, electricity generated from renewables or low carbon sources is becoming more desirable for households.

- Off-grid communities are willing to consider community-based energy schemes, provided that they are in-keeping with surroundings, financially viable and offer network resilience (interviewees were not necessarily aware of the specific term but understood the concept).

- Whilst environmental sustainability is important to many of the households we spoke to, the viability of a decarbonisation solution is dependent on financial feasibility, this is especially important for less affluent households.
    - Improved access to grants and increases in the amounts available (i.e. an increase in the value of the Boiler Upgrade Grant), or other forms of funding, would likely increase uptake in decarbonisation options.

- Some wealthier households were attached to their current ways of doing things, such as continuing to burn wood and run a diesel generator. There was a sense of security in what was familiar and considered ‘low risk’.

7.0 References

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APPENDIX A House Data

A.1 Story 1

Figure A-1: Indicative image representative of Story 1.

Table A-1: A summary of the house details for Story 1

House details	
Building Type	Detached
Construction Age	pre 1919
Stock type	House
Location	Rural - isolated
Grid connection	Not connected to gas or electric grid
Energy source(s)	Diesel generator, bottled gas, wind turbine, solar PV, BESS
Property Fabric	Single glazing, poor insulation standards

Table A-2: Property dimensions for Story 1.

Dimensions	
Storeys	2 (rooms in loft)
Width	14.5 m
Depth	11 m
Ground floor height	2.4 m
First floor height	2.1 m
Front Glazing Ratio	22%
Back Glazing Ratio	18%
Ground floor area	143 m^2
First floor area	50 m^2
Number of exposed sides	4
External wall area front	42 m^2
External wall area back	42 m^2
External wall area sides	51 m^2

Dimensions	
Solid door area front	4.0 m^2
Front Glazing area (West)	9.2 m^2
Back Glazing area (East)	7.4 m^2

Table A-3: Summary of current services available at the property for Story 1.

Services (+ hot water, controls, vent.)	
Fuel	Solid
SAP main heating	Solid fuel boiler
Main heating description	Solid fuel independent boiler (1990s)
Efficiency	55.0%
Manufactured date	1984 to current
Index	700029
Heat emitter	Systems with radiators
Hot water description	From main heating system
Hot water storage (litres)	300
Ventilation description	Natural ventilation
Heating control	No time or thermostatic control of room temperature

Table A-4: Summary of the property fabric for Story 1.

Fabric	
Wall description	Solid wall
Wall U value	1.7 W/m^2/K
Wall thermal mass	250
Floor description	Uninsulated floor
Floor U value	2.0 W/m^2/K
Roof description	300mm insulation
Roof U value	0.14 W/m^2/K
Glazing description	Single Glazing
Glazing U value	4.8 W/m^2/K
Infiltration (Q50)	10

Table A-5: Summary of the renewable systems available for the property in Story 1.

Renewables	
Solar PV	6 kWp
Solar Thermal (m^2)	0
Electric battery	13.5 kW

A.2 Story 2

Figure A-2: Indicative image representative of Story 2.

Table A-6: A summary of the house details for Story 2.

House details	
Building Type	Detached
Construction Age	Pre1960s
Stock type	Bungalow
Location	Village edge
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Solar PV, heat pump, BESS

Table A-7: Property dimensions for Story 2.

Dimensions	
Storeys	1
Width	15 m
Depth	11 m
Ground floor height	2.4 m
First floor height	N/A
Front Glazing Ratio	25.5%
Back Glazing Ratio	24.6%
Ground floor area	125 m^2
First floor area	N/A
Number of exposed sides	4
External wall area front	27 m^2
External wall area back	27 m^2
External wall area sides	53 m^2
Solid door area front	4.0 m^2
Front Glazing area (West)	9.2 m^2
Back Glazing area (East)	8.9 m^2

Table A-8: Summary of current services available at the property for Story 2.

Services (+ hot water, controls, vent.)	
Fuel	Electricity
SAP main heating	Heat pump
Main heating description	Heat Pump - Vaillant aroTHERM 5kW
Efficiency	272.0%
Manufactured date	current
Index	102606
Heat emitter	Underfloor heating, pipes in insulated timber floor
Hot water description	From main heating system
Hot water storage (litres)	150
Ventilation description	natural ventilation
Heating control	Time and temperature zone control

Table A-9: Summary of the property fabric for Story 2.

Fabric	
Wall description	Cavity Wall filled insulation
Wall U value	0.6 $W/m^2/K$
Wall thermal mass	250
Floor description	Uninsulated floor
Floor U value	2.0 $W/m^2/K$
Roof description	300mm insulation
Roof U value	0.14 $W/m^2/K$
Glazing description	Double Glazing
Glazing U value	2.8 $W/m^2/K$
Infiltration (Q50)	10

Table A-10: Summary of the renewable systems available for the property in Story 2.

Renewables	
Solar PV	3.5 kWp
Solar Thermal (m^2)	0
Electric battery	13.5 kW

A.3 Story 3

Figure A-3: Indicative image representative of Story 3.

Table A-11: A summary of the house details for Story 3.

House details	
Building Type	Semi-detached
Construction Age	Pre1960s
Stock type	Ground floor flat
Location	Village
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Ground source heat pump, solar PV

Table A-12: Property dimensions for Story 3.

Dimensions	
Storeys	1
Width	10 m
Depth	5 m
Ground floor height	2.4 m
First floor height	N/A
Front Glazing Ratio	22%
Back Glazing Ratio	18%
Ground floor area	50 m^2
First floor area	N/A
Number of exposed sides	2
External wall area front	19 m^2

Dimensions	
External wall area back	20 m^2
External wall area sides	12 m^2
Solid door area front	2.0 m^2
Front Glazing area (West)	5.3 m^2
Back Glazing area (East)	2.1 m^2

Table A-13: Summary of current services available at the property for Story 3.

Services (+ hot water, controls, vent.)	
Fuel	Electricity
SAP main heating	Heat pump
Main heating description	Heat Pump - 5kW
Efficiency	272.0%
Manufactured date	current
Index	102606
Heat emitter	Underfloor heating, pipes in insulated timber floor
Hot water description	From main heating system
Hot water storage (litres)	150
Ventilation description	Natural ventilation
Heating control	Time and temperature zone control

Table A-14: Summary of the property fabric for Story 3.

Fabric	
Wall description	Cavity wall
Wall U value	1.5 $W/m^2/K$
Wall thermal mass	250
Floor description	Uninsulated floor
Floor U value	2.0 $W/m^2/K$
Roof description	300mm insulation
Roof U value	0.14 $W/m^2/K$
Glazing description	Double Glazing
Glazing U value	2.8 $W/m^2/K$
Infiltration (Q50)	10

Table A-15: Summary of the renewable systems available for the property in Story 3.

Renewables	
Solar PV	2 kWp
Solar Thermal (m^2)	0
Electric battery	0

A.5 Story 4

Figure A-4: Indicative image representative of Story 4.

Table A-16: A summary of the house details for Story 4.

House details	
Building Type	Semi-detached
Construction Age	1960s
Stock type	House
Location	Town
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Mains electric

Table A-17: Property dimensions for Story 4.

Dimensions	
Storeys	2
Width	8 m
Depth	6 m
Ground floor height	2.4 m
First floor height	2.2 m
Front Glazing Ratio	25%
Back Glazing Ratio	25%
Ground floor area	48 m^2
First floor area	48 m^2
Number of exposed sides	2
External wall area front	27 m^2

Dimensions	
External wall area back	28 m^2
External wall area sides	28 m^2
Solid door area front	2.0 m^2
Front Glazing area (West)	9.4 m^2
Back Glazing area (East)	9.1 m^2

Table A-18: Summary of current services available at the property for Story 4.

Services (+ hot water, controls, vent.)	
Fuel	Electricity
SAP main heating	Electric storage system
Main heating description	Off-peak tariffs - Old storage heaters
Efficiency	100%
Manufactured date	0
Index	Off-peak tariffs - Old (large volume) storage heaters
Heat emitter	Systems with radiators
Hot water description	Electric immersion (on-peak or off-peak)
Hot water storage (litres)	300
Ventilation description	Natural ventilation
Heating control	Manual charge control

Table A-19: Summary of the property fabric for Story 4.

Fabric	
Wall description	Cavity Wall filled insulation
Wall U value	0.6 $W/m^2/K$
Wall thermal mass	250
Floor description	Uninsulated floor
Floor U value	2.0 $W/m^2/K$
Roof description	300mm insulation
Roof U value	0.14 $W/m^2/K$
Glazing description	Double Glazing
Glazing U value	2.8 $W/m^2/K$
Infiltration (Q50)	10

Table A-20: Summary of the renewable systems available for the property in Story 4.

Renewables	
PV	0 kWp
Solar Thermal (m^2)	0 m^2
Electric Battery	0

A.7 Story 5

Figure A-5: Indicative image representative of Story 5.

Table A-21: A summary of the house details for Story 5.

House details	
Building Type	Detached
Construction Age	Pre 1919
Stock type	House
Location	Rural
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Solar PV, oil

Table A-22: Property dimensions for Story 5.

Dimensions	
Storeys	2
Width	9 m
Depth	9 m
Ground floor height	2.4 m
First floor height	2.4 m
Front Glazing Ratio	22%
Back Glazing Ratio	18%
Ground floor area	81 m^2
First floor area	81 m^2
Number of exposed sides	2
External wall area front	34 m^2
External wall area back	36 m^2
External wall area sides	22 m^2
Solid door area front	4.0 m^2

Dimensions	
Front Glazing area (West)	9.5 m^2
Back Glazing area (East)	7.6

Table A-23: Summary of current services available at the property for Story 5.

Services (+ hot water, controls, vent.)	
Fuel	Oil
SAP main heating	Gas oil boiler
Main heating description	Oil combi boiler (new)
Efficiency	78.3%
Manufactured date	1996 to current
Index	2035
Heat emitter	Systems with radiators
Hot water description	From main heating system
Hot water storage (litres)	0
Ventilation description	Natural ventilation
Heating control	Programmer, room thermostat and TRVs

Table A-24: Summary of the property fabric for Story 5.

Fabric	
Wall description	Solid wall
Wall U value	1.7 W/m2/K
Wall thermal mass	250
Floor description	Uninsulated floor
Floor U value	2.0 W/m2/K
Roof description	300mm insulation
Roof U value	0.14 W/m2/K
Glazing description	Single Glazing
Glazing U value	4.8 W/m2/K
Infiltration (Q50)	10

Table A-25: Summary of the renewable systems available for the property in Story 5.

Renewables	
Solar PV	4 kWp
Solar Thermal (m^2)	0 m^2
Electric Battery	0

A.9 Story 6

Figure A-6: Indicative image representative of Story 6.

Table A-26: A summary of the house details for Story 6.

House details	
Building Type	Detached
Construction Age	Pre 1919
Stock type	House
Location	Village
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Oil, mains electric

Table A-27: Property dimensions for Story 6.

Dimensions	
Storeys	2
Width	9 m
Depth	7 m
Ground floor height	2.4 m
First floor height	2.4 m
Front Glazing Ratio	22%
Back Glazing Ratio	18%
Ground floor area	63 m^2
First floor area	63 m^2
Number of exposed sides	2
External wall area front	34 m^2

Dimensions	
External wall area back	36 m^2
External wall area sides	17 m^2
Solid door area front	2.0 m^2
Front Glazing area (West)	9.5 m^2
Back Glazing area (East)	7.6 m^2

Table A-28: Summary of current services available at the property for Story 6.

Services (+ hot water, controls, vent.)	
Fuel	Oil
SAP main heating	Gas oil boiler
Main heating description	Oil boiler
Efficiency	85.0%
Manufactured date	up to 1990
Index	2034
Heat emitter	systems with radiators
Hot water description	From main heating system
Hot water storage (litres)	150
Ventilation description	natural ventilation
Heating control	No time or thermostatic control of room temperature

Table A-29: Summary of the property fabric for Story 6.

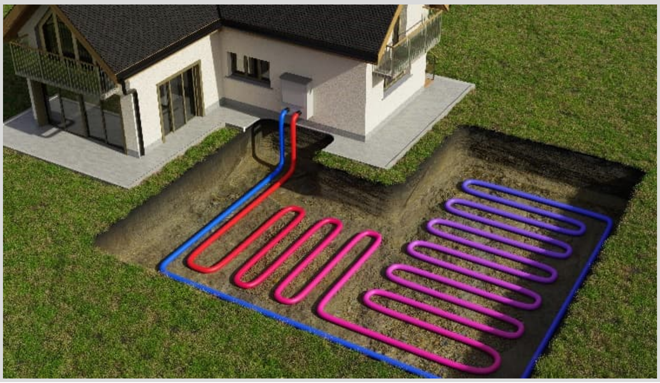
Fabric	
Wall description	Solid wall
Wall U value	1.7 W/m2/K
Wall thermal mass	250
Floor description	Uninsulated floor
Floor U value	2.0 W/m2/K
Roof description	300mm insulation
Roof U value	0.14 W/m2/K
Glazing description	Single Glazing
Glazing U value	4.8 W/m2/K
Infiltration (Q50)	10

Table A-30: Summary of the renewable systems available for the property in Story 6.

Renewables	
Solar PV	0 kWp
Solar Thermal	0 m^2
Electric Battery	0 kW

APPENDIX B Visual Glossary

Table B-1: Visual Representation of Terms Used

Definition	Visual Representation
Air Source Heat Pump	
Ground Source Heat Pump	
Battery Energy Storage Systems (BESS)	
Biomass Boiler	

Definition	Visual Representation
Horizontal Axis Wind Turbine (HAWT)	
Solar Photovoltaics (Solar PV)	
Vertical Axis Wind Turbine (VAWT)	

APPENDIX C Case Study Summaries

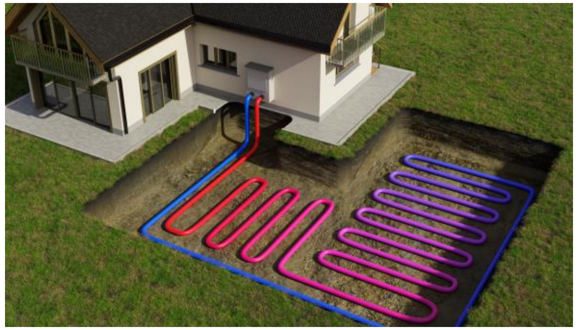
Off grid case studies

6th February 2025

EIC
Together we innovate
Northern Powergrid
Northern Gas Networks
Sheffield Hallam University
Centre for Regional Economic and Social Research
Thornton Tomasetti
UCL Institute for Environmental Design and Engineering
Cardiff University
Prifysgol Caerdydd

Visual Glossary

Air Source Heat Pump



Ground Source Heat Pump

Solar PV

Vertical Axis Wind Turbine

Horizontal Axis Wind Turbine

Battery Energy Storage System

Biomass Boiler

Case Study 1

Rural farmhouse, no young children, off grid, national park, private rent

In a nutshell

Motivation and willingness: Keen to decarbonise, mainly for financial reasons

Barriers and ability to decarbonise: Financial barriers; access to trained professionals; planning regulations; dependency on landlord.

House Details	
Building type	Detached
Construction age	pre 1919
Stock type	House
Location	Rural - isolated
Grid connection	Not connected to gas or electric grid
Energy source(s)	Diesel generator, bottled gas, wind turbine, solar PV, BESS
Fabric	Single glazing, poor insulation standards

Case Study 1

Component:	Baseline	House As Is	Anticipated Retrofit to 2030	Decarbonisation Retrofit to 2030
Walls	Limestone walls, problems with render	Limestone walls, problems with render	**Limestone walls with 100mm internal insulation**	Limestone walls with 100mm internal insulation
Roof	300mm insulation	300mm insulation	300mm insulation	**400mm insulation**
Floor	No upgrade	No upgrade	No upgrade	**50mm over floor insulation**
Window & Doors	Single glazing	Single glazing	**Standard high performance (upvc)**	**Triple Glazing composite (timber)**
Heating and Hot Water	Solid fuel back burner, with large inefficient hot water tank	Solid fuel back burner, with large inefficient hot water tank	**Oil Combi boiler**	**Heat pump and tank**
Airtightness & Ventilation	Normal practice	Normal practice	**Good practice**	Good practice
Results				
SAP Rating	41	59	65	89
EPC Band	E	D	D	B
Fuel Bills	£2,425	£1,674	£1,434	£465
Decarbonised vs.1990		40%	64%	96%
Retrofit Costs			£32,000	£42,000
Disruption Factor			Medium	Very High

Case Study 1

Description	Details	Possible Grants	Approximate Cost (£)	
			Without Grant	With Grants
Air Source Heat Pump & BESS Capacity Increase	• In conjunction with suggested retrofits to ensure maximum efficiency • Requires additional compatible hot water cylinder • If existing renewables are less than required supply, additional sources may be required • An increase in the BESS capacity would be required to supply the input energy demand of the heat pump	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'	Approximately **£8,500**[1] (excluding additional BESS costs)	£1000
Ground Source Heat Pump & BESS Capacity Increase	• In conjunction with suggested retrofits to ensure maximum efficiency • Requires additional compatible hot water cylinder • If existing renewables are less than required supply, additional sources may be required • An increase in the BESS capacity would be required to supply the input energy demand of the heat pump	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'	Up to **£35,000**[2] (excluding additional BESS costs)	£27,500
BESS Capacity Increase	• An increase in the BESS capacity could meet the electrical demands of the property • The installation and maintenance cost will be dependent on the BESS capacity required	NA	Unknown	

Case Study 2

Rural brick house, off gas, homeowners, retired environmentalists

In a nutshell

Motivation and willingness: Keen to decarbonise, especially for financial reasons

Barriers and ability to decarbonise: Access to trained professionals; planning regulations

House Details	
Building type	Detached
Construction age	pre 1960s
Stock type	Bungalow
Location	Village edge
Grid connection	Not connected to gas, connected to electric grid
Energy source(s)	Solar PV, BESS, Heat Pump
Fabric	Double glazing, average insulation standard

Case Study 2

Component:	Baseline	House As Is	Anticipated Retrofit to 2030	Decarbonisation Retrofit to 2030
Walls	Brick cavity wall	**Brick cavity wall with insulation**	Brick cavity wall with insulation	Brick cavity wall with insulation
Roof	300mm insulation	300mm insulation	300mm insulation	**400mm insulation**
Floor	No upgrade	No upgrade	No upgrade	**Floor insulation**
Window & Doors	Double glazing	Double glazing	**Standard high performance (upvc)**	**Triple Glazing composite (timber)**
Heating and Hot Water	Oil boiler with hot water tank	**Heat pump**	Heat pump	Heat pump
Airtightness & Ventilation	Normal practice	Normal practice	Good practice	Good practice
Results				
SAP Rating	35	57	59	84
EPC Band	F	D	D	B
Fuel Bills	£1,935	£1,249	£1,181	£471
Decarbonised vs.1990		87%	87%	93%
Retrofit Costs			£16,000	£22,000
Disruption Factor			Medium	Very High

Case Study 2

Description	Details	Possible Grants	Approximate Cost (£)	
			Without Grant	With Grants
VAWT	• Single wall or roof mounted VAWT (2 kW) • This would require an approximate area of 2.6 m^2 available for siting • Note that this will not provide the full electrical requirement for the household	NA	Up to **£4,000**	NA
VAWT	• 5 wall or roof mounted VAWT (2 kW) • Increase to 40.5 kW BESS capacity • This would require an approximate area of 16 m^2 available for siting • The installation would require approval from the local authority		Up to **£32,000**	
VAWT	• Single standalone VAWT (18 m mast height, 7.5 kW) • Increase to 40.5 kW BESS capacity • This would require an approximate area of 26 m^2 available for siting • Potential for **up to £430 - £860 generated per year** • The installation would require approval from the local authority		Up to **£55,000**	
Community Based Scheme	• 600 m^2 of solar PV (fixed axis, 0.2 MW array) • 4 mid-size HAWT (80 kW) • 400 kW BESS • This would require buy in from the community, and an approximate area of 2240 m^2 available for siting) • There would be significant maintenance costs associated with a site of this scale • Cost per household would likely be too high for the scheme to be viable		Up to £304,000[3] (**£7,600** per household)	

Case Study 3

Rural flat, off gas, social rent, disability, fuel poverty

In a nutshell

Motivation and willingness: Keen to decarbonise for financial and environmental reasons

Barriers and ability to decarbonise: Dependency on landlord; financial; local infrastructure

House Details	
Building type	Semi-detached
Construction age	Pre 1919
Stock type	Ground floor flat
Location	Village
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Ground Source Heat Pump, solar PV
Fabric	Double glazing, average insulation standard

Case Study 3

Component:	Baseline	House As Is	Anticipated Retrofit to 2030	Decarbonisation Retrofit to 2030
Walls	Limestone walls	Limestone walls	**Limestone walls with 100mm internal insulation**	Limestone walls with 100mm internal insulation
Roof	300mm insulation	300mm insulation	300mm insulation	**400mm inuslation**
Floor	No upgrade	No upgrade	No upgrade	**50mm over floor insulation**
Window & Doors	Double glazing	Double glazing	**Standard high performance (upvc)**	**Triple Glazing composite (timber)**
Heating and Hot Water	Oil boiler hot water tank	**Heat pump and tank**	Heat pump and tank	Heat pump and tank
Airtightness & Ventilation	Normal practice	**Good practice**	Good practice	Good practice
Results				
SAP Rating	52	55	67	85
EPC Band	E	E	D	B
Fuel Bills	£774	£732	£540	£251
Decarbonised vs.1990		87%	89%	93%
Retrofit Costs			£24,000	£28,000
Disruption Factor			High	Very High

Case Study 3

Description	Details	Possible Grants	Approximate Cost (£)	
			Without Grant	With Grants
BESS	• BESS (10 kW) • This would require an approximate area of 0.2 m^2 available for siting (outdoor, garage and can be wall mounted)	NA	**£5000 to £7500**	NA
Community Based Scheme	• 750 m^2 of solar PV (fixed axis, 134 kW array) • 2 mid-size HAWT (80 kW) • 1.0 MW BESS • This would require buy in from the community, and an approximate area of 1625 m^2 available for siting) • There would be significant maintenance costs associated with a site of this scale	NA	Up to £340,000[4] (**£6800** per household)	NA
Community Based Scheme	• 1500 m^2 of solar PV (fixed axis, 0.27 MW array) • 800 kW BESS • This would require buy in from the community, and an approximate area of 1660 m^2 available for siting) • There would be significant maintenance costs associated with a site of this scale	NA	Up to £560,000[4] (**£11,2000** per household)	NA
Community Based Scheme	• 4 mid-size HAWT (80 kW) • 1.2 MW BESS • This would require buy in from the community, and an approximate area of 1590 m^2 available for siting) • Note that this is unlikely to be approved by local planning authorities	NA	Up to £520,000[4] (**£10,400** per household)	NA

Case Study 4

Urban semi, off gas, family, social rent, saving on heating

In a nutshell

Motivation and willingness: Willing to decarbonise to save money

Barriers and ability to decarbonise: Financial; dependency on landlord; habits and preference for high temperatures

House Details	
Building type	Semi-detached
Construction age	1960s
Stock type	House
Location	Town
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Mains electric
Fabric	Double glazing, average standard insulation

Case Study 4

Component:	Baseline	House As Is	Anticipated Retrofit to 2030	Decarbonisation Retrofit to 2030
Walls	Brick cavity wall with insulation	Brick cavity wall with insulation	Brick cavity wall with insulation	Brick cavity wall with insulation
Roof	300mm insulation	300mm insulation	300mm insulation	**400mm insulation**
Floor	No upgrade	No upgrade	No upgrade	**Floor insulation**
Window & Doors	Double glazing	Double glazing	**Standard high performance (upvc)**	**Triple Glazing composite (timber)**
Heating and Hot Water	Storage heaters	Storage heaters	**Heat pump**	Heat pump
Airtightness & Ventilation	Normal practice	Normal practice	**Good practice**	Good practice
Results				
SAP Rating		17	78	90
EPC Band		G	C	B
Fuel Bills		£2,252	£528	£231
Decarbonised vs.1990		82%	94%	96%
Retrofit Costs			£27,000	£32,000
Disruption Factor			High	Very High

Case Study 4

Description	Details	Possible Grants	Approximate Cost (£)	
			Without Grant	**With Grants**
Community Based Scheme	• 2000 m² of solar PV (fixed axis, 350 kW array) • 3 mid-size HAWT (80 kW) • 1.2 MW BESS • This would require buy in from the community, and an approximate area of 3400 m² available for siting) • There would be significant maintenance costs associated with a site of this scale	NA	Up to £907,000[5,6] (**£18,145** per household)	NA
Community Based Scheme	• 3000 m² of solar PV (fixed axis, 0.53 MW array) • 600 kW BESS • This would require buy in from the community, and an approximate area of 3305 m² available for siting) • There would be significant maintenance costs associated with a site of this scale		Up to £820,000[5,6] (**£16,400** per household)	
Community Based Scheme	• 8 mid-size HAWT (80 kW) • 1.2 MW BESS • This would require buy in from the community, and an approximate area of 3155 m² available for siting) • Note that this is unlikely to be approved by local planning authorities		Up to £640,000[5] (**£13,600** per household)	
Solar PV & Air Source Heat Pump & BESS	• Solar PV (4 kW array) • Air source heat pump, although this would be dependent on pipework compatibility • In conjunction with suggested retrofits to ensure maximum efficiency	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'	Up to **£17,300**	£9,800

Case Study 5

Detached stone house, off gas, homeowners, retired older couple

In a nutshell

Motivation and willingness: Willing to reduce carbon emission while balancing other needs such as habits, aesthetics and value for money.

Barriers and ability to decarbonise: Habit; planning; expert advice

House Details	
Building type	Detached
Construction age	Pre 1919
Stock type	House
Location	Rural
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Solar PV, oil, BESS
Fabric	Single glazing, average insulation standards

Case Study 5

Component:	Baseline	House As Is	Anticipated Retrofit to 2030	Decarbonisation Retrofit to 2030
Walls	Limestone walls	Limestone walls	**Limestone walls with 100mm internal insulation**	Limestone walls with 100mm internal insulation
Roof	300mm insulation	300mm insulation	300mm insulation	**400mm insulation**
Floor	No upgrade	No upgrade	No upgrade	**50mm over floor insulation**
Window & Doors	Single glazing	Single glazing	**Standard high performance (upvc)**	**Triple Glazing composite (timber)**
Heating and Hot Water	Solid fuel back burner, with large inefficient hot water tank	**Oil Combi boiler**	Oil Combi boiler	**Heat pump and tank**
Airtightness & Ventilation	Normal practice	Normal practice	**Good practice**	Good practice
Results				
SAP Rating	53	58	74	90
EPC Band	E	D	C	B
Fuel Bills	£1,654	£1,472	£935	£355
Decarbonised vs.1990		50%	65%	96%
Retrofit Costs			£23,000	£35,000
Disruption Factor			High	Very High

Case Study 5

Description	Details	Possible Grants	Approximate Cost (£)	
			Without Grant	With Grants
HVO	• Requires fuel storage • Potential to reduce CO_2 emissions by up to 90%, but it is not an entirely 'clean' energy source • Supply could be affected by severe weather events • Can expect a 10-15% cost increase compared to the existing oil	NA	-	NA
Biomass Boiler	• Requires fuel storage • Not an entirely 'clean' energy source, but potential to be CO_2 neutral, depending on fuel sourcing • Estimated annual fuel cost of up to £575	Eligible for £5000 grant under the 'Boiler Upgrade Scheme'	Up to **£20,000**	£15,000
Air Source Heat Pump	• In conjunction with suggested retrofits to ensure maximum efficiency • Dependent on pipework compatibility • Would likely require an additional electric source, which could be provided by the mains electric connection, or additional renewable sources	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'	Approximately **£8,500**[1] (excluding additional BESS costs)	£1000
Ground Source Heat Pump	• In conjunction with suggested retrofits to ensure maximum efficiency • Dependent on pipework compatibility • Would likely require an additional electric source, which could be provided by the mains electric connection, or additional renewable sources	Eligible for £7500 grant under the 'Boiler Upgrade Scheme'	Up to **£35,000**[2]	£27,500

Case Study 6

Old detached house, oil boiler, homeowners, couple with one child

In a nutshell

Motivation and willingness: Willingness and a desire to improve the energy efficiency of the house, mainly for financial reasons and for warmth.

Barriers and ability to decarbonise: Financial barriers, as well as reluctance to engage in disruptive renovations.

House Details	
Building type	Detached
Construction age	Pre 1919
Stock type	House
Location	Village
Grid connection	Not connected to gas grid, connected to electric grid
Energy source(s)	Oil, mains electric
Fabric	Single glazing, average insulation

Case Study 6

Component:	Baseline	House As Is	Anticipated Retrofit to 2030	Decarbonisation Retrofit to 2030
Walls	Limestone walls	Limestone walls	**Limestone walls with 100mm internal insulation**	Limestone walls with 100mm internal insulation
Roof	300mm insulation	300mm insulation	300mm insulation	**400mm insulation**
Floor	No upgrade	No upgrade	No upgrade	**50mm over floor insulation**
Window & Doors	Single glazing	Single glazing	**Standard high performance (upvc)**	**Triple Glazing composite (timber)**
Heating and Hot Water	Oil boiler	Oil boiler	Oil Combi boiler	**Heat pump and tank**
Airtightness & Ventilation	Normal practice	Normal practice	**Good practice**	Good practice
Results				
SAP Rating		44	77	91
EPC Band		E	C	B
Fuel Bills		£1,643	£681	£251
Decarbonised vs.1990		24%	51%	94%
Retrofit Costs			£30,000	£39,000
Disruption Factor			High	Very High

Case Study 6

Description	Details	Possible Grants	Approximate Cost (£)	
			Without Grant	With Grants
New Gas Connection	• Provided that a property uptake of 30% is met (estimated to be 9 – 12 properties) • Not a 'clean' energy, but will provide sufficient heating	NA	TBC	NA
HVO	• Requires fuel storage • Potential to reduce CO_2 emissions by up to 90%, but it is not an entirely 'clean' energy source • Supply could be affected by severe weather events • Can expect a 10-15% cost increase compared to the existing oil		-	
Biomass Boiler	• Requires fuel storage • Not an entirely 'clean' energy source, but potential to be CO_2 neutral, depending on fuel sourcing • Estimated annual fuel cost of up to £575	Eligible for £5000 grant under the 'Boiler Upgrade Scheme'	Up to **£20,000**	£15,000
Solar PV Heating System	• Would require installation of an immersion heater • 3.5 kW solar PV array • To ensure continuous heating and hot water supply a BESS (14 kW) system would be required	NA	Up to **£30,500**	NA

Footnotes

1. Approximate cost for a £8500 but air to air heat pump is £8500 but could cost up to £14,000.
2. The cost associated with a ground source heat pump can vary widely, depending on the specifics of installation at the property.
3. Approximate, assuming 40 households and an average electrical demand of 5700 kWh per household annually, and accounting for future EV use. Not including maintenance costs, or EV infrastructure (i.e. charging points). It is assumed that thermal demands of the properties are met outside of this scheme.
4. Approximate, assuming 50 households and an average electrical demand of 5700 kWh per household annually, and accounting for future EV use. Not including maintenance costs, or EV infrastructure (i.e. charging points). It is assumed that thermal demands of the properties are met outside of this scheme.
5. Approximate, assuming 30 households and an average energy (electrical and thermal) demand of 18400 kWh per household annually, and accounting for future EV use. Not including maintenance costs, or EV infrastructure (i.e. charging points). It is assumed that thermal demands of the properties are met outside of this scheme.
6. Note that during the transition period for this scheme, dependent on the season/solar irradiance, there is likely to be insufficient energy for the initial period.