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LGUK – Scottish Archetype Analysis

9th July 2021

Executive summary

This analysis compares the relative suitability of various heating methods between three Scottish archetype properties.

The methods of heating considered include: oil boilers, coal boilers, LPG boilers, bioLPG boilers, ASHPs, hybrid systems, and biomass boilers.

The suitability will depend on three factors:

1. The cost to the consumer
2. The consumer income
3. The ease of the transition

Introduction

In line with net-zero emissions targets and the resulting necessity to decarbonise the housing sector, the Scottish Government is in the process of outlining regulations on the sale of new, carbon intensive heating systems.

Specifically, households not connected to the gas grid often depend on higher carbon sources of heating, such as oil and coal. Banning the sale of these highly carbon intensive forms of heating in the imminent future, provides the fastest decarbonisation pathway to a net-zero heating system. However, the low-carbon alternatives often come at a high capital cost and low-income households are prohibited in their ability to transition to an expensive low-carbon alternative such as a heat pump. LPG is a fossil fuel, but with a much lower carbon intensity to oil and gas. BioLPG, being produced from more sustainable feedstocks, provides an even lower carbon alternative. BioLPG boilers can therefore be offered as an attractive compromise. Being a low-carbon heating source and available at low capital costs, bioLPG boilers offer a more financially feasible low-carbon heating source for many households, particularly low-income households.

The following report outlines analysis which compares the capital, operational and levelized costs of various low-carbon heating systems to determine which is the most financially attractive to households. The analysis compares three different archetype properties and assesses the relative suitability of each heating system. It also considers the ‘consumer journey’, addressing how the hassle of transitioning to a new heating system is also within consumer interest.

Results

Archetype 1:

- Detached house
- Pre-1918
- Floor area: 198 m^2
- No major renovations (assume solid walled – uninsulated, some room-in roof loft insulation)
- Energy needed for heating: 142 kWh/m^2*year (28,116 kWh/year)
- Comparable to archetype #13 from the Scottish Government report[1,2] (There are over 20,228 properties that correspond to this archetype)

Cost Breakdown:

Table 1 - Archetype 1:

Heating System	CapEx (£)	OpEx (£/yr) [2020]	Levelized Cost (£/MWh) [2020]	Carbon Emissions (kgCO2e/yr) [2020]
Oil Boiler	4,150	2,096	77	10,493
Coal Boiler	6,093	1,868	75	14,665
LPG Boiler	2,000	2,777	92	7,438
BioLPG Boiler	2,000	3,276	**108**	1,689
ASHP	18,270	3,040	139	2,433
ASHP (+R) *	30,990	**1,216**	158	973
Hybrid	14,960	2,886	131	2,284
Hybrid (+R) *	31,270	1,335	170	988
Biomass Boiler	18,100	2,325	113	**686**

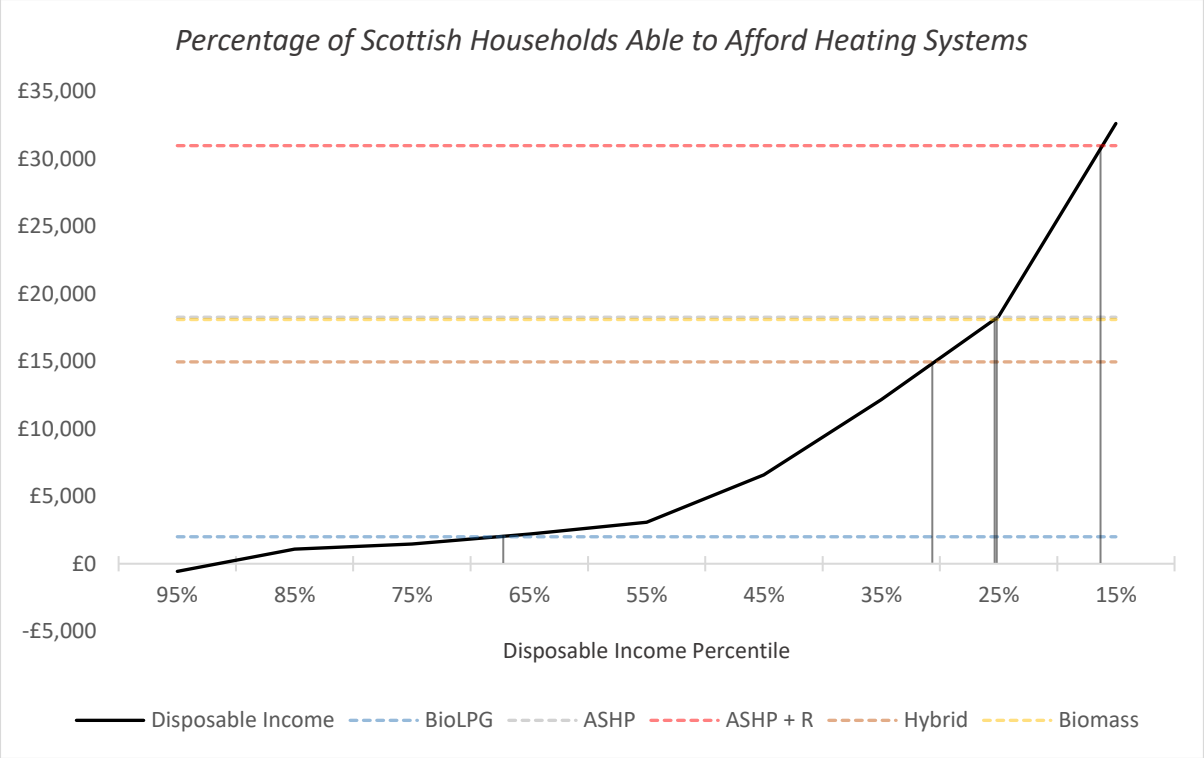
***Archetype 1 renovations:** loft insulation (£3,100), solid wall insulation (£11,500), UPVC double glazing (£8,300) – total capital: (£22,900).

New cost of ASHP (+R) = £8,090. New cost of hybrid system (+R) = £8,370

Analysis:

- The lowest capital cost heating system is a bioLPG boiler. All other (low-carbon) heating systems require a substantially higher upfront cost, with the next lowest cost system (hybrid), being over seven times more expensive.
- The heating system with lowest operational cost is ASHP + R (with renovations), followed closely by a hybrid system + R. However, the upfront cost of these systems, with expensive renovation costs, are highly prohibitive.
- As well as having the lowest capital cost, bioLPG boilers have the lowest levelized cost of any low-carbon heating system. This means that, not only are they the most affordable heating system with respect to upfront cost, but they are also the most cost-effective heating option over the system's lifetime.
- For this archetype, due to the very high cost of renovation, the levelized costs for the ASHP/hybrid + R are higher than without renovations.
- BioLPG boilers also have the fourth lowest carbon intensity of any of the low-carbon heating systems, with significantly lower emissions than any of the high carbon heating systems.

Deriving heating system affordability via household disposable income:



Graph 1: The line graph in black shows the percentage of Scottish households existing within a certain annual disposable income range. The dashed lines are constants representing the upfront cost of each heating system. The point at which the dashed lines intersect the solid black line indicates how affordable each heating option is, with the percentage of households able to afford the system displayed along the x-axis.

Heating System (CapEx)	Percentage of households who can afford the capital cost:
BioLPG Boiler (£2,000)	**67%**
ASHP (£18,270)	25%
ASHP + R (£30,990)	16%
Hybrid (£14,960)	31%
Biomass (£18,100)	25%

Table 2: Displays the approximate percentage of Scottish households that have an annual disposable income greater than the capital cost of each of the low-carbon heating systems, for the archetype 1 property.

Consumer Journey:

Consumer journey measures the amount of time required throughout all stages of the installation process of a new system, indicating the amount of hassle associated with each option.

Heating System	Research, Search and Contact (hours)	Pre-Installation (hours)	Installation (Days)	Post-Installation (hours)	Ongoing (hours per year)	Approximate Total Time:
BioLPG:	4-8	3.5-8	0.5	6-16	1-2	**2.5 – 4.5 days**
Biomass:	10-18	3.5-8	1	7-17	1-3.5	3.5 – 6 days
ASHP:	10-18	3.5-14	2-5	7-80	1-3.5	4.5 – 6 days
ASHP + R:	10-18	3.5-14	17.25-20.25	7-80	1-3.5	22 - 26 days
Hybrid:	10-18	3.5-14	2-5	7-80	1-3.5	4.5 – 6 days
Hybrid + R:	10-18	3.5-14	17.25-20.25	7-80	1-3.5	22 - 26 days

Table 3: Displays the consumer journey of each heating system for the archetype 1 property.[3]

Archetype 1 – renovation time:
Loft insulation (0.25 days), solid wall insulation (10 days) and UPVC double glazing (5 days).

Archetype 2:

- Terraced house
- 1965-1980
- Floor area: 85 m^2
- No major renovations (assume cavity wall with no insulation)
- Energy needed for heating: 96 kWh/m^2*year (8,160 kWh/year)
- Comparable to archetype #17 from the Scottish Government report – but applied to an off-grid setting[1,2].

Cost Breakdown:

Table 4 - Archetype 2:

Heating System	CapEx (£)	OpEx (£/yr) [2020]	Levelized Cost (£/MWh) [2020]	Carbon Emissions (kgCO2e/yr) [2020]
Oil	3,950	863	92	4,317
Coal	3,375	769	81	6,034
LPG Boiler	1,500	1,175	99	3,060
BioLPG Boiler	1,500	1,386	**116**	695
ASHP	7,930	1,195	137	957
ASHP (+R) *	8,275	**685**	123	548
Hybrid	9,050	1,150	147	904
Hybrid (+R) *	9,675	725	145	545
Biomass	9,534	956	124	**282**

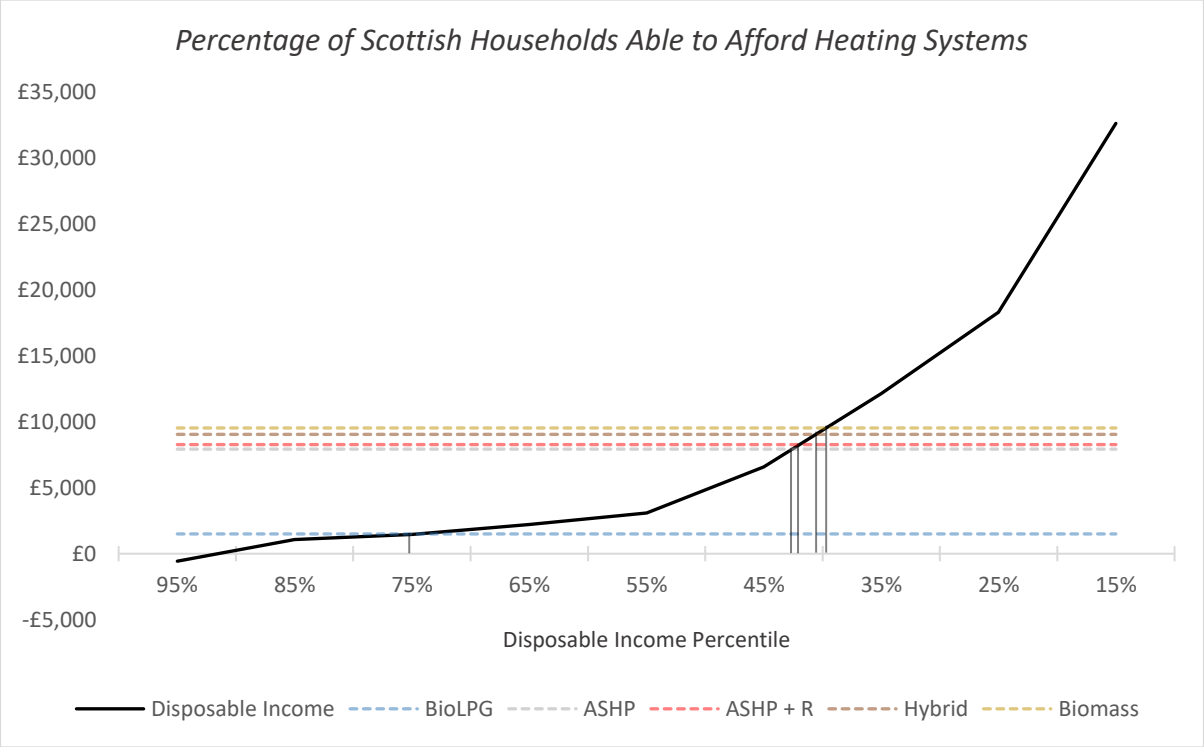
***Archetype 2 renovations**: loft insulation (£1,900), cavity wall insulation (£505) – total capital (£2,405).

New cost of ASHP (+R) = £5,870. New cost of hybrid system (+R) = £7,270.

Analysis:

- The lowest capital cost heating system is again the bioLPG boiler. All other low-carbon heating options have upfront costs at least five times higher.
- The heating system with the lowest operational cost is an ASHP + R system, followed closely by a hybrid + R. These cheap to run systems however, have the highest upfront costs of any system, potentially making them prohibited to a select consumer income range.
- Despite having the highest operation costs, bioLPG boilers have the lowest levelized cost of any low-carbon heating system due to the low capital costs.
- BioLPG boilers also prove to be a much less carbon intensive option than oil, coal or LPG boilers, with emissions over four times lower.

Deriving heating system affordability via household disposable income:



Graph 2: The line graph in black shows the percentage of Scottish households existing within a certain annual disposable income range. The dashed lines are constants representing the upfront cost of each heating system. The point at which the dashed lines intersect the solid black line indicates how affordable each heating option is, with the percentage of households able to afford the system displayed along the x-axis.

Heating System (CapEx)	Percentage of households who can afford the capital cost:
BioLPG Boiler (£1500)	**75%**
ASHP (£7,930)	43%
ASHP + R (£8,275)	42%
Hybrid (£9,050)	41%
Biomass (£9,534)	40%

Table 5: Displays the approximate percentage of Scottish households that have an annual disposable income greater than the capital cost of each of the low-carbon heating systems, for the archetype 2 property.

Consumer Journey:

Consumer journey measures the amount of time required throughout all stages of the installation process of a new system, indicating the amount of hassle associated with each option.

Heating System	Research, Search and Contact (hours)	Pre-Installation (hours)	Installation (Days)	Post-Installation (hours)	Ongoing (hours per year)	Approximate Total Time:
BioLPG:	4-8	3.5-8	0.5	6-16	1-2	**2.5 – 4.5 days**
Biomass:	10-18	3.5-8	1	7-17	1-3.5	3.5 – 6 days
ASHP:	10-18	3.5-14	2-5	7-80	1-3.5	4.5 – 6 days
ASHP + R:	10-18	3.5-14	2.5-5.5	7-80	1-3.5	5 – 6.5 days
Hybrid:	10-18	3.5-14	2-5	7-80	1-3.5	4.5 – 6 days
Hybrid + R:	10-18	3.5-14	2.5-5.5	7-80	1-3.5	5 – 6.5 days

Table 6: Displays the consumer journey of each heating system for the archetype 2 property.[3]

Archetype 2 - renovations:
Loft insulation (0.25 days) and cavity wall insulation (0.25 days).

Archetype 3:

- Semi-detached house
- 1965-1980
- Floor area: 123 m^2
- No major renovations (assume cavity wall with no insulation)
- Energy needed for heating: 137 kWh/m^2*year (16,851 kWh/year)
- Comparable to archetype #1 from the Scottish Government report – but applied to an off-grid setting[1,2].

Cost Breakdown

Table 7 – Archetype 3:

Heating System	CapEx (£)	OpEx (£/yr) [2020]	Levelized Cost (£/MWh) [2020]	Carbon Emissions (kgCO2e/yr) [2020]
Oil	3,950	1,264	84	6,324
Coal	5,098	1,126	82	8,839
LPG Boiler	1,700	1,696	96	4,483
BioLPG Boiler	1,700	2,001	**112**	1,018
ASHP	10,650	1,782	135	1,427
ASHP (+R) *	11,980	**1,216**	122	973
Hybrid	9,870	1,706	133	1,345
Hybrid (+R) *	12,440	1,249	132	952
Biomass	13,650	1,401	123	**414**

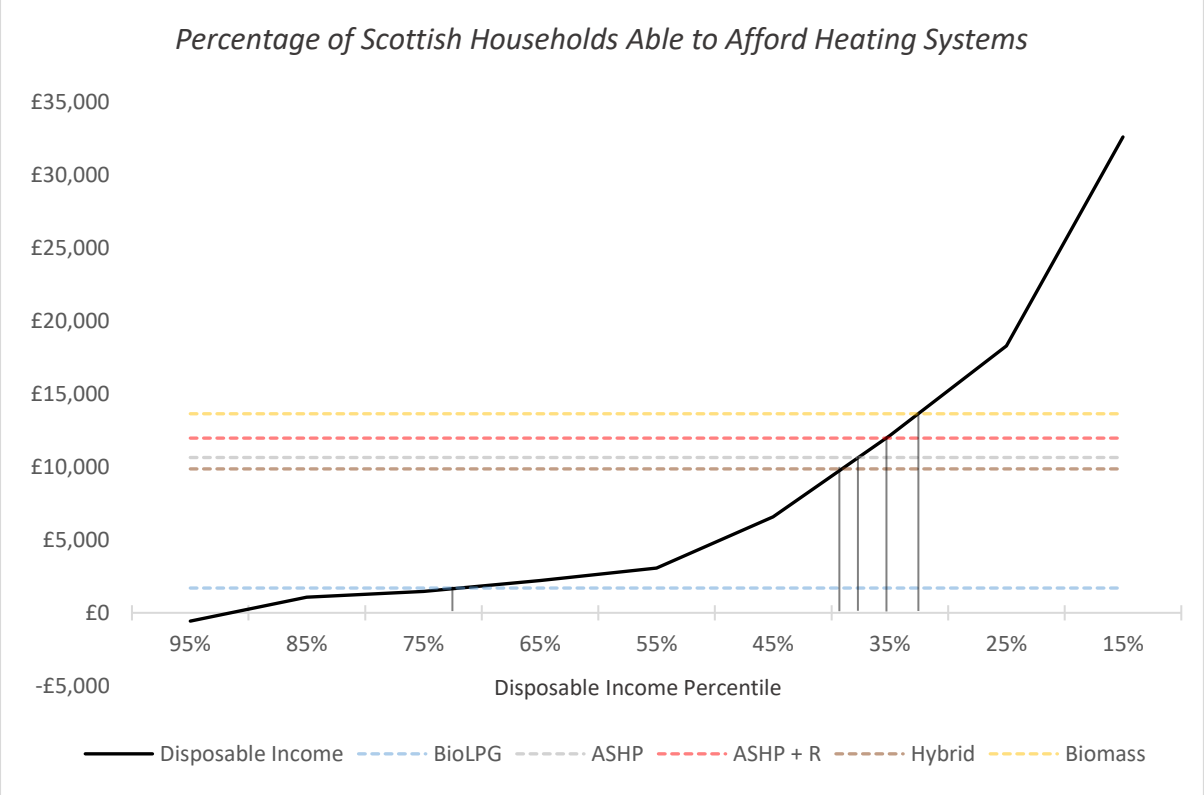
***Archetype 3 renovation time:** loft insulation (£3,100), cavity wall insulation (£905) – total capital (£4,050).

New cost of ASHP (+R) = £7,930. New cost of hybrid system (+R) = £8,390.

Analysis:

- The lowest capital cost heating system for archetype 3 is again a bioLPG boiler. All other low-carbon heating options have upfront costs over five times higher.
- The heating system with the lowest operational cost is the ASHP + R system, followed closely by a hybrid + R system.
- Once again, bioLPG boilers have the lowest levelized cost of any low-carbon heating system, consistently proving itself to be the most affordable option over the system's lifetime, for all three archetypes.
- BioLPG boilers also provide a low-carbon heating option for archetype 3, with only biomass, hybrid + R and ASHP + R systems having slightly lower carbon intensities. BioLPG is also a clean burning fuel with low air pollutants, unlike biomass for example, which results in a significant quantity of PM, SOx and NOx emissions.

Deriving heating system affordability via household disposable income:



Graph 3: The line graph in black shows the percentage of Scottish households existing within a certain annual disposable income range. The dashed lines are constants representing the upfront cost of each heating system. The point at which the dashed lines intersect the solid black line indicates how affordable each heating option is, with the percentage of households able to afford the system displayed along the x-axis.

Heating System (CapEx)	Percentage of households who can afford the capital cost:
BioLPG Boiler (£1,700)	**72%**
ASHP (£10,650)	37%
ASHP + R (£11,980)	35%
Hybrid (£9,870)	39%
Biomass (£13,650)	32%

Table 8: Displays the approximate percentage of Scottish households that have an annual disposable income greater than the capital cost of each of the low-carbon heating systems, for the archetype 3 property.

Consumer Journey:

Consumer journey measures the amount of time required throughout all stages of the installation process of a new system, indicating the amount of hassle associated with each option.

Heating System	Research, Search and Contact (hours)	Pre-Installation (hours)	Installation (Days)	Post-Installation (hours)	Ongoing (hours per year)	Approximate Total Time:
BioLPG:	4-8	3.5-8	0.5	6-16	1-2	**2.5 – 4.5 days**
Biomass:	10-18	3.5-8	1	7-17	1-3.5	3.5 – 6 days
ASHP:	10-18	3.5-14	2-5	7-80	1-3.5	4.5 – 6 days
ASHP + R:	10-18	3.5-14	3.25-6.25	7-80	1-3.5	8 – 12 days
Hybrid:	10-18	3.5-14	2-5	7-80	1-3.5	4.5 – 6 days
Hybrid + R:	10-18	3.5-14	3.25-6.25	7-80	1-3.5	8 - 12 days

Table 9: Displays the consumer journey of each heating system for the archetype 3 property.[3]

Archetype 3 – renovation time:
Loft insulation (0.25 days) and cavity wall insulation (1 day).

Discussion of Results

Heating system cost:

From a consumer perspective, the cost of a heating system is usually the primary consideration in driving heating system choice.

This cost can be divided into the upfront capital cost of the heating system and the ongoing operational costs. Consumers will pay a higher upfront cost if it results in lower ongoing costs and they are able to break-even on their higher initial investment within a sufficiently short time-period.

The levelized cost of the heating system encompasses both the capital and operational cost and is therefore a useful measure of the financial attractiveness of the system, with the lower levelized costs being of greater appeal.

This analysis has found the annualised capital expenditure, the operational expenditure and the resulting levelized cost of various heating systems for three contrasting property archetypes.

The heating system types can be divided into ‘carbon intensive’ forms of heating and ‘low-carbon’ forms of heating. Often, the carbon intensive forms of heating prove to be more financially attractive than the low carbon alternative, however, in line with Scottish Government announcements, these carbon intensive options are not considered to be a viable option and exist only for the sake of comparison.

For all three archetypes (defined above), bioLPG boilers consistently demonstrated to be the cheapest option when defined by both capital and levelized cost. This means that they are the most affordable in terms of upfront cost to the consumer, as well as the most cost-effective option over the heating system’s lifetime.

Renovating the properties to improve their thermal efficiencies, alongside the installation of an air-source heat pump is usually advised. This is to allow them to operate more efficiently and provide lower operational costs. The same is true for a hybrid heating system. For archetype properties two and three, these renovations resulted in significantly lower operational costs and reduced the overall levelized cost, (compared with the non-renovation option). However, for archetype 1, despite significantly reducing the operational expenditure, because the cost of the necessary renovations is so high, the levelized cost actually increased for this option.

Heating system affordability via household disposable income:

The option of paying a higher capital cost for lower operational costs and long-term financial gain, beyond the breakeven point, is considered differently depending on a household’s level of disposable income. Whilst one heating system may provide a lower levelized cost and greater financial gain over the system’s lifetime, the capital cost may be prohibitive to lower income households. Capital cost is therefore an important metric to analyse to determine the heating system’s short term financial accessibility. This was done here by comparing the capital cost with household disposable income.

The household disposable income was derived from the household gross income using the following formula:

The household gross income was taken from the Scottish Government's 'Additional poverty analysis 2021' publication. This publication uses unequivalised gross annual household income data taken from the 2018 Family Resource Survey HBAI dataset, which are categorised into deciles[4,5].

For each gross income decile, an expected 'household cost' was derived, consisting of housing (rent/mortgage payments), as well as fuel and power costs, and this was then subtracted from the corresponding gross income decile. The additional 'typical spending' of each income decile was also predicted and subtracted from the gross income, resulting in a final 'household disposable income' value.

The affordability of the heating system was then defined. This affordability measure relies on two assumptions:

1. The household income of all three archetypes can be represented equivalently by the national income average.
2. If the capital cost of a heating system exceeds the annual disposable income of a household it is deemed 'not affordable'.

Realistically, the household incomes will vary between the three archetypes. A more tailored archetype income analysis would demand a more detailed dataset of Scottish Household Income by property type.

The results of the analysis show that bioLPG boilers are a more affordable option to a significantly higher proportion of Scottish households than any other low-carbon heating system.

For archetype 1, bioLPG boilers were found to be affordable to **67%** of households in Scotland, compared to the next most affordable heating system option, Hybrid, only being affordable to 31% of households.

For archetype 2, bioLPG boilers were found to be affordable to **75%** of households in Scotland, compared to the next most affordable heating system option, ASHP, affordable to 43% of households.

For archetype 3, bioLPG boilers were found to be affordable to **72%** of households in Scotland, compared to the next most affordable heating system option, Hybrid, being affordable to just 39% of households.

These results demonstrate bioLPG boilers to consistently have far more accessible upfront costs compared with any other low-carbon heating system option.

Consumer Journey:

The other important consideration from a consumer point of view is the 'consumer journey'. This is here defined by the amount of time required to organise the replacement of the old system, the time required for the installation/renovation process, the ongoing maintenance requirements over the system's lifetime, and the regularity at which the system needs

replacing. Effectively, the consumer journey measures the convenience of the overall operation, which can also impact on the consumer's choice of heating system.

The amount of time for each stage of the process was estimated for each heating system and for each archetype, based off estimated ranges made in a previous study that considered the consumer journey in detail.[3]

For the heating systems which include renovations (ASHP + R and hybrid + R), these renovation times were also included.

These renovation times for each archetype varied significantly; 15.25 days for archetype 1, 0.5 days for archetype 2 and 1.25 days for archetype 3. These renovation times were determined by adding together the amount of time predicted for each aspect of the renovation process.

For all three archetypes, bioLPG boilers prove to have the shortest amount of time required by the consumer throughout the installation process. The operational lifetime of a bioLPG boiler, at 15 years, is slightly less than a biomass boiler, at 20 years, and a ASHP (+R) system, at 18 years, meaning over a 60-year period it may need replacing one more time. However, such long time periods are of less concern to most consumers.

Overall, bioLPG boilers provide an attractive consumer journey compared with other low-carbon heating system options, with low-labour requirements required over the course of the installation process.

Additional Consideration - costs of electrical supply and network upgrades:

Additional to the direct consumer cost of installing a new heating system, it is important to consider the consumer and network costs associated with upgrading electricity supply. Single phase electricity supply is more prominent in Scottish homes. This poses a challenge for the installation of certain larger heat pumps, and needs addressing to prevent malfunctions of other electrical appliances.[6]

Not all installations require connection upgrades, but typically in properties with a large peak heat demand (100-150 W/m_2 and higher), which require a larger heat pump, upgrades to 3 phase supply are a realistic requirement. This adds to the upfront capex for the consumer, with upgrades varying in price but typically costing more than £3,000 per job.[7]
Additionally, DNOs are facing local network costs associated with the integrating electric vehicles and heat systems. Whilst disruption is less of a challenge and cost in rural areas, analysis suggests that DNOs will need to upgrade over 130,000 km of underground or overground cable – a greater length of network than DNOs serving urban areas.[8]

Summary of Results:

1. Cost Breakdown:

BioLPG boilers consistently demonstrated to have the lowest capital cost of any low-carbon heating system, making them the most accessible low-carbon heating option with the majority of households from each archetype being able to afford the capital.

Despite having slightly higher operational costs, bioLPG boilers also have the lowest levelized cost of any low-carbon heating system, making them the most affordable option over the system's lifetime.

2. Sustainability:

BioLPG boilers have carbon emissions over four times lower than any of the high-carbon heating systems (oil, coal and LPG boilers). With the present-day carbon intensity of electricity supply, they also result in less carbon equivalent emissions than both ASHP and hybrid systems. Despite not having as low a carbon intensity as biomass boilers, bioLPG is a much cleaner burning fuel with far fewer air pollutant emissions.

3. Consumer Journey:

BioLPG boilers also prove to have the most appealing 'consumer journey' with less time required over the total installation process than any other low-carbon heating system option.

References:

[1]: Technical Feasibility of Low Carbon Heating in Domestic Buildings – Scottish Government report (2020) *Element Energy*.

[2]: TABULA Web Tool: TABULA WebTool (building-typology.eu)

[3]: Holdaway, E., Samuel, B., Greenleaf, J., Briden, A. and Gardiner, A. (2009) "The Hidden costs and benefits of domestic energy efficiency and carbon saving measures" *ECOFYS*.

[4]: Rural Scotland Key Facts (2021) – People and Communities Services and Lifestyle Economy and Enterprise, *National Statistics*.

[5]: Additional Poverty Analysis (2021) *The Scottish Government.*

[6] Kensa Heat Pumps (2015) *Heat Pumps and Single Phase Power.*

[7] UK Power Networks (2021) *Upgrade electricity: Time and cost*

[8] Vivid Economics and Imperial College (2018) *Accelerated electrification and the GB electricity system.*

Appendix:

[9]: BEIS (2018) Energy Company Obligation – Eco3: 2018-2022, Final Stage Impact Assessment.

[10]: LPG Gas Boiler & Central Heating Costs 2021 Price Comparison (householdquotes.co.uk)

[11]: BEIS (2018) Non-Domestic RHI and Domestic RHI monthly deployment data.

[12]: Element Energy (2017) Hybrid Heat Pump, report for BEIS.

[13]: SAP 10.0 (2018) The Government's Standard Assessment Procedure for Energy Rating of Dwellings.

[14]: CCC (2019) Net Zero Technical Report.

[15]: DEFRA (2018) UK Government GHG Conversion Factors for Company Reporting.

Appendix:

Capital Costs:

Heating System:	Cost:
Oil Condensing Boiler 12 kW	£2,100[9]
Oil Condensing Boiler 13-24 kW	£2,700[9]
Oil Condensing Boiler 25-36 kW	£2,900[9]
Oil Tank	£1,250
Coal Boiler <25 kW	£251 /kW
Coal Boiler 25-50 kW	£174 /kW
Gas Condensing Boiler 12kW	£1,500[9]
Gas Condensing Boiler 13-15kW	£1,600[9]
Gas Condensing Boiler 16-18kW	£1,700[9]
Gas Condensing Boiler 19-24kW	£1,900[9]
Gas Condensing Boiler 25-28kW	£2,000[9]
LPG Tank Rental	*£65 / year*[10]
Biomass Boiler 10kW and below	£8,120[11]
Biomass Boiler 11-15kW	£9,534[11]
Biomass Boiler 16-20kW	£11,544[11]
Biomass Boiler 21-25kW	£13,650[11]
Biomass Boiler 26-30kW	£18,100[11]
Hybrid Heat Pump <5kW	£1,285 / kW[12]
Hybrid Heat pump 5-11kW	£625 / kW[12]
Hybrid Boiler	£1,000[12]
Hybrid Installation Cost	£2,600[12]
ASHP 3kW (A2 + R)	£5,870[11]
ASHP 7kW (A2 / A3 + R)	£7,930[11]
ASHP 7.5kW (A1 + R)	£8,090[11]
ASHP 11kW (A3)	£10,650[11]
ASHP 20kW (A1)	£18,270[11]

Fuel Price:

Heating Fuel:	Fuel Price[13]:
Electricity	0.1756 £/kWh
Electricity – off-peak tariff	0.1490 £/kWh
Conventional LPG	0.0785 £/kWh
LPG (BioLPG premium included)	0.0926 £/kWh
BioLPG Cylinder Fuel (Hybrid System)	0.1187 £/kWh
BioLPG Premium	*0.0141 £/kWh*
Oil	0.0418 £/kWh
Coal	0.0435 £/kWh
Biomass	0.0510 £/kWh

Heating Lifetimes:

Heating System:	Heating Lifetime[9, 14]:
Oil Condensing Boiler	15 years
Coal Boiler	15 years
Gas Condensing Boiler	15 years
Biomass Boiler	20 years
ASHP	18 years
Hybrid	15 years

Carbon Intensity Factors:

Heating Fuel:	Carbon Intensity[15]
Electricity	0.2831 kgCO2e/kWh
LPG	0.2145 kgCO2e/kWh
BioLPG	0.0487 kgCO2e/kWh
Coal	0.3447 kgCO2e/kWh
Heating Oil	0.2467 kgCO2e/kWh
Biomass	0.0151 kgCO2e/kWh