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LGUK – English Archetype Analysis

7th July 2021

Executive summary

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

The methods of heating considered include: oil boilers, coal boilers, LPG boilers, bioLPG boilers, air source heat pumps, hybrid systems and biomass boilers.

The suitability will depend on three factors:

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

Introduction

As the UK works towards a net-zero greenhouse gas emissions by 2050 target, the residential heating sector is required to phase out high-carbon forms of heating and replace with low-carbon heating technologies. Homes not connected to the gas grid, often use more carbon intensive forms of heating, primarily oil boilers. The imminent replacement of these systems therefore represents the fastest route to heat decarbonisation. Approximately 14% of English homes are not connected to the gas grid, representing over three million homes.[1]

Low-carbon alternatives however, 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 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, they provide 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:

- 1945-1964 Terrace House
- Current heating: oil boiler
- No major renovations (cavity walls uninsulated, loft uninsulated)
- Floor area: 88m2
- Annual heating demand: 13,165 kWh / year
- There are approximately 7,330 English properties that correspond to this archetype[2,3]

Cost Breakdown:

Table 1 - Archetype 1:

Heating System	CapEx (£)	OpEx (£/yr) [2020]	Levelized Cost (£/MWh) [2020]	Carbon Emissions (kgCO2e/yr) [2020]
Oil Boiler	3,950	975	89	4,878
Coal Boiler	4,391	869	84	6,817
LPG Boiler	1,600	1,321	98	3,458
BioLPG Boiler	1,600	1,558	**114**	785
ASHP	8,270	1,474	142	1,180
ASHP (+R) *	13,375	**670**	157	536
Hybrid	9,430	1,383	148	1,101
Hybrid (+R) *	14,675	714	179	536
Biomass Boiler	11,544	1,081	128	**319**

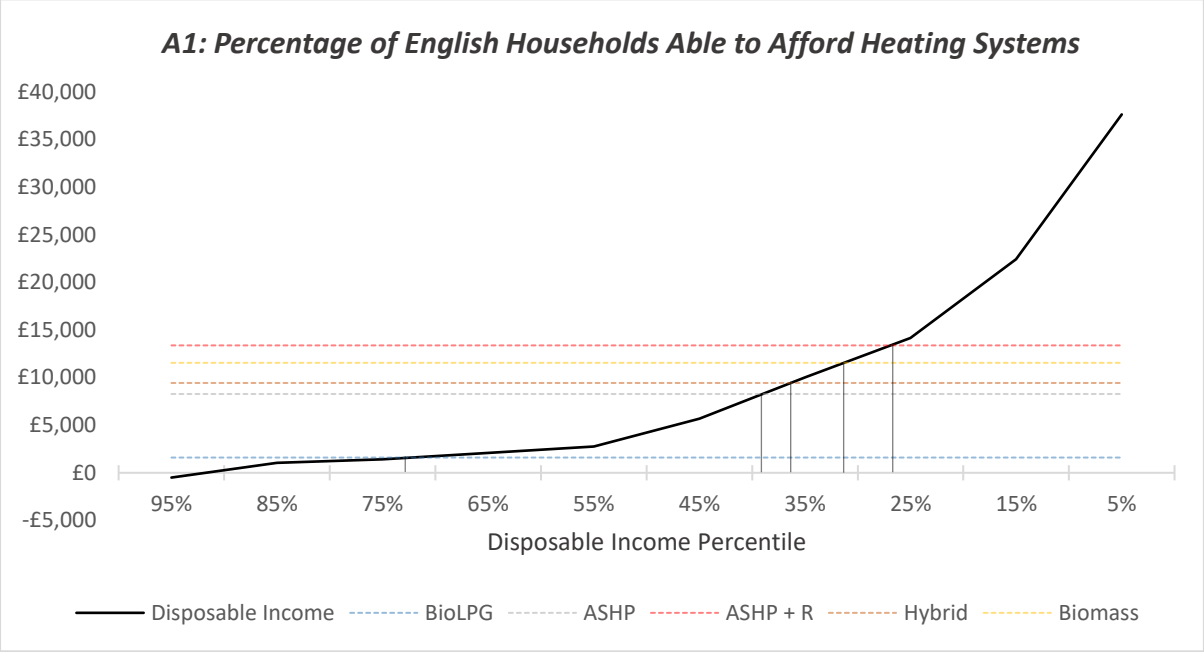
***Archetype 1 renovations:** loft insulation (£1,900), cavity wall insulation (£505), UPVC double glazing (£5,000) – total capital: (£7,405).

New cost of ASHP (+R) = £5,970. New cost of hybrid system (+R) = £7,270.

Analysis:

- The lowest capital cost heating system is the bioLPG boiler. All other (low-carbon) heating systems require a substantially higher upfront cost, with the next lowest cost system (ASHP), being over five 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 additional renovation costs, limit their sale to high income households.
- BioLPG boilers have the lowest levelized cost of any low-carbon heating system. Despite not having the lowest operational costs, the very low capital costs result in bioLPG boilers being the most cost-effective heating system over their lifetime. For this archetype, due to the cost of renovation, the levelized costs for the ASHP/hybrid systems with renovations 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 English 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 (£1,600)	**73%**
ASHP (£8,270)	39%
ASHP + R (£13,375)	26%
Hybrid (£9,430)	36%
Biomass (£11,544)	31%

Table 2: Displays the approximate percentage of English 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	**3.5 – 7.5 days**
Biomass:	10-18	3.5-8	1	7-17	1-3.5	5.5 – 10.5 days
ASHP:	10-18	3.5-14	2-5	7-20	1-3.5	6.5 – 16 days
ASHP + R:	10-18	3.5-14	5-8	7-20	1-3.5	9.5 – 19 days
Hybrid:	10-18	3.5-14	2-5	7-20	1-3.5	6.5 – 16 days
Hybrid + R:	10-18	3.5-14	5-8	7-20	1-3.5	9.5 – 19 days

Table 3: Displays the consumer journey of each heating system for the archetype 1 property.[4]

Archetype 1 – renovation time:
Loft insulation (1 day), cavity wall insulation (1 day) and UPVC double glazing (1 day). Total 3 days.

Archetype 2:

- 1919-1944 Detached House
- Current heating: oil boiler
- No major renovations (solid brick uninsulated, loft uninsulated)
- Floor area: 153m2
- Annual heating demand: 22,338 kWh / year
- There are approximately 42,000 English properties that correspond to this archetype[2,3]

Cost Breakdown:

Table 4 - Archetype 2:

Heating System	CapEx (£)	OpEx (£/yr) [2020]	Levelized Cost (£/MWh) [2020]	Carbon Emissions (kgCO2e/yr) [2020]
Oil Boiler	4,150	1,658	80	8,299
Coal Boiler	5,077	1,478	76	11,599
LPG Boiler	1,900	2,208	94	5,883
BioLPG Boiler	1,900	2,605	**110**	1,336
ASHP	13,060	2,472	137	1,979
ASHP (+R) *	29,690	**1,023**	177	818
Hybrid	13,300	2,329	138	1,850
Hybrid (+R) *	30,470	1,109	192	825
Biomass Boiler	18,100	1,839	123	**543**

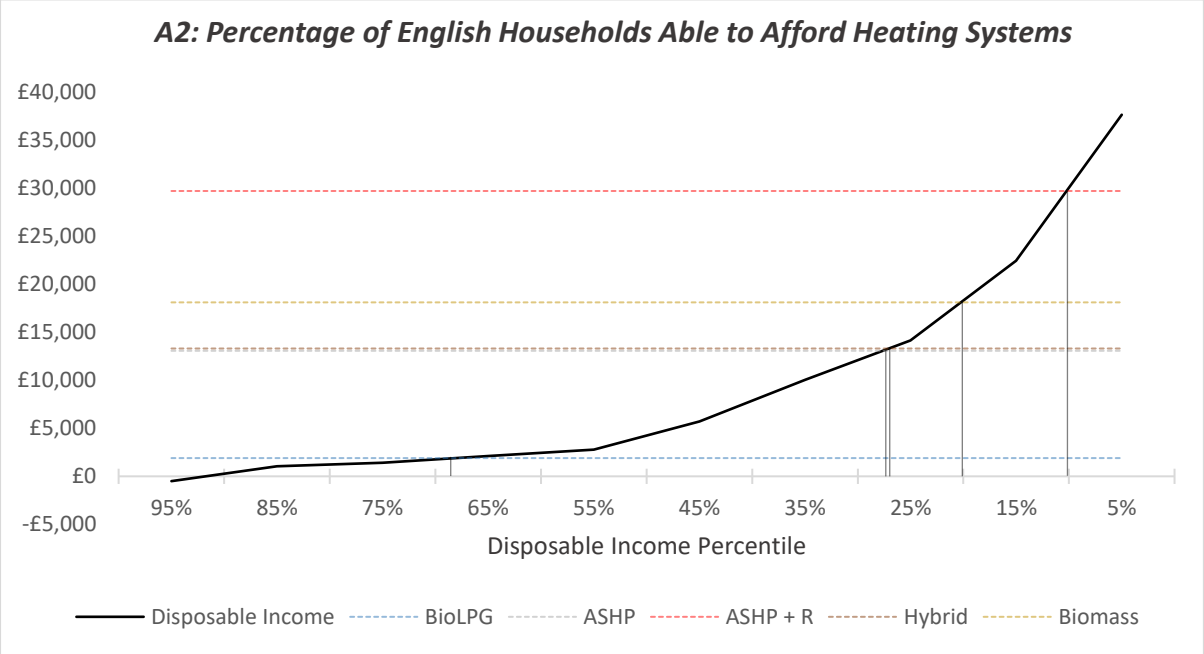
***Archetype 2 renovations**: loft insulation (£2,300), solid wall insulation (£11,500), double glazing (£8,300) – total capital (£22,100).

New cost of ASHP (+R) = £7,590. New cost of hybrid system (+R) = £8,370.

Analysis:

- The lowest capital cost heating system is again the bioLPG boiler. All other low-carbon heating options have upfront costs at least six times higher.
- The heating system with the lowest operational cost is an ASHP + R system, followed closely by a hybrid system + R. These cheap to run systems however, have the highest upfront costs of any system, limiting them to a high consumer income range.
- BioLPG boilers again have the lowest levelized cost of any heating system, due to their combination of low capital cost and reasonably low operational cost.
- Carbon equivalent emissions resulting from the use of bioLPG boilers are found to be over four times lower than any of the high-carbon heating systems and with the present-day electricity supply, is also less carbon intensive than ASHP and hybrid systems.

Deriving heating system affordability via household disposable income:



Graph 2: The line graph in black shows the percentage of English 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 (£1,900)	**68%**
ASHP (£13,060)	27%
ASHP + R (£29,690)	10%
Hybrid (£13,300)	27%
Biomass (£18,100)	20%

Table 5: Displays the approximate percentage of English 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	**3.5 – 7.5 days**
Biomass:	10-18	3.5-8	1	7-17	1-3.5	5.5 – 10.5 days
ASHP:	10-18	3.5-14	2-5	7-20	1-3.5	6.5 – 16 days
ASHP + R:	10-18	3.5-14	14-17	7-20	1-3.5	18.5 – 28 days
Hybrid:	10-18	3.5-14	2-5	7-20	1-3.5	6.5 – 16 days
Hybrid + R:	10-18	3.5-14	14-17	7-20	1-3.5	18.5 – 28 days

Table 6: Displays the consumer journey of each heating system for the archetype 2 property.[4]

Archetype 2 - renovations:
Loft insulation (1 day), solid wall insulation (10 days) and UPVC double glazing (1 day). Total 12 days.

Archetype 3:

- 1981-1990 Detached House
- Current heating: oil boiler
- No major renovations (cavity wall uninsulated, loft uninsulated)
- Floor area: 127m2
- Annual heating demand: 15,011 kWh / year
- There are approximately 32,000 English properties that correspond to this archetype[2,3]

Cost Breakdown

Table 7 – Archetype 3:

Heating System	CapEx (£)	OpEx (£/yr) [2020]	Levelized Cost (£/MWh) [2020]	Carbon Emissions (kgCO2e/yr) [2020]
Oil Boiler	3,950	1,144	85	5,728
Coal Boiler	4,754	1,020	77	8,005
LPG Boiler	1,500	1,541	96	4,060
BioLPG Boiler	1,500	1,818	**112**	922
ASHP	8,270	1,384	115	1,108
ASHP (+R) *	11,140	**987**	127	790
Hybrid	9,430	1,389	119	1,071
Hybrid (+R) *	12,420	1,050	183	788
Biomass Boiler	11,544	1,269	116	**375**

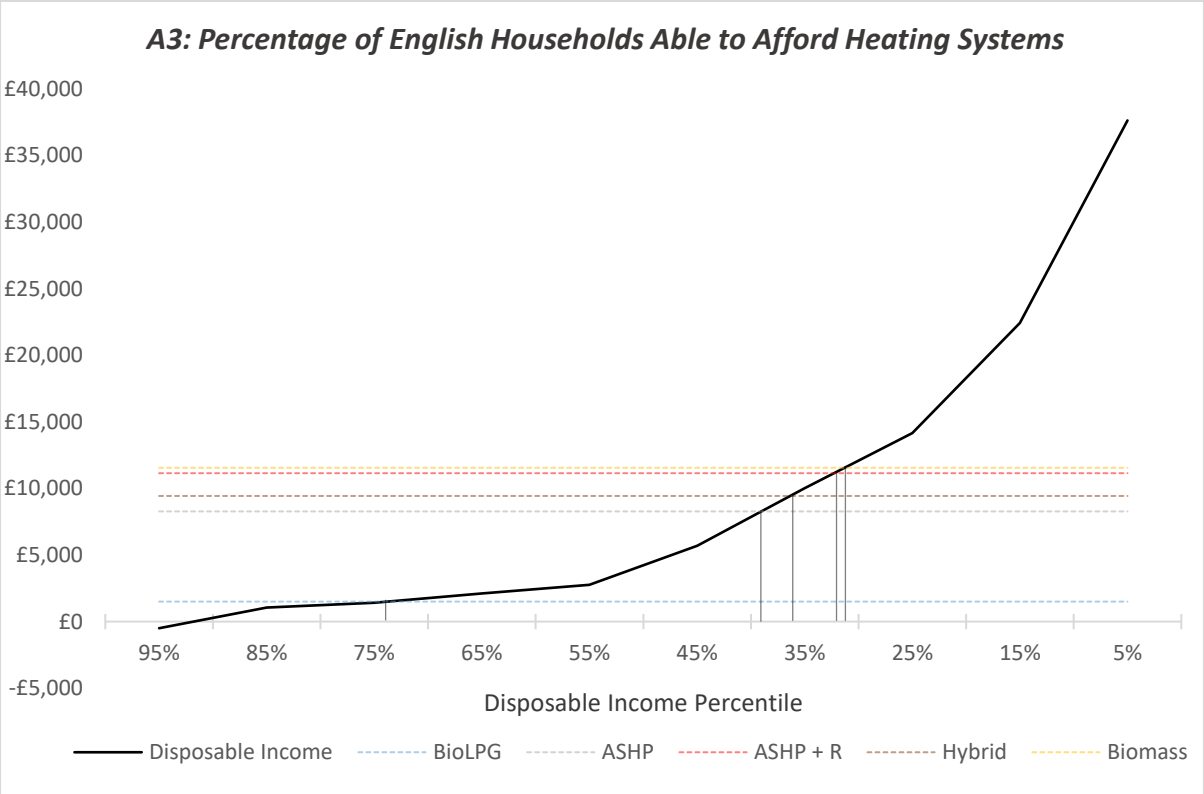
***Archetype 3 renovation time:** loft insulation (£3,100), cavity wall insulation (£950) – total capital (£4,050).

New cost of ASHP (+R) = £7,090. New cost of hybrid system (+R) = £8,370.

Analysis:

- BioLPG boilers again have by far the lowest capital cost of any low-carbon heating system with all other low-carbon heating options have upfront costs over five times higher than bioLPG boiler systems.
- The heating system with the lowest operational cost is the ASHP + R system, followed closely by a hybrid system + R.
- 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 marginally lower carbon intensities. It has a carbon intensity over four times lower than an LPG boiler making it a far more sustainable option than any of the high carbon heating systems.

Deriving heating system affordability via household disposable income:



Graph 3: The line graph in black shows the percentage of English 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 (£1,500)	**74%**
ASHP (£8,270)	39%
ASHP + R (£11,140)	33%
Hybrid (£9,430)	36%
Biomass (£11,544)	31%

Table 8: Displays the approximate percentage of English 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	**3.5 – 7.5 days**
Biomass:	10-18	3.5-8	1	7-17	1-3.5	5.5 – 10.5 days
ASHP:	10-18	3.5-14	2-5	7-20	1-3.5	6.5 – 16 days
ASHP + R:	10-18	3.5-14	4-7	7-20	1-3.5	8.5 – 18 days
Hybrid:	10-18	3.5-14	2-5	7-20	1-3.5	6.5 – 16 days
Hybrid + R:	10-18	3.5-14	4-7	7-20	1-3.5	8.5 – 18 days

Table 9: Displays the consumer journey of each heating system for the archetype 3 property.[4]

Archetype 3 – renovation time:

Loft insulation (1 days) and cavity wall insulation (1 day). Total time 2 days

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 net-zero targets, 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 are consistently demonstrated to be the cheapest option when defined by both capital cost and levelized cost. This means that they are the most accessible option from an upfront cost point of view, but also prove to be the most affordable low-carbon heating system over their lifetimes.

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 heat pump system. However, for the three archetype properties considered here, these renovations, despite lowering heat demand and operational costs, actually resulted in an overall higher levelized cost, (compared with the non-renovation option). This is due to the significant increase in upfront cost included in the renovation options, particularly for archetype 2 – demanding expensive solid wall insulation.

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 in order 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:

Household Disposable Income = ***Household Gross Income*** – ***Household Costs*** – ***Typical Spending***

Household gross income data from 2020 was taken from the office for National Statistics and was used to derive gross income deciles, which measure the proportion of households earning above or below a specified gross income.[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.[6]

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 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 English households than any other low-carbon heating system.

For archetype 1, bioLPG boilers were found to be affordable to **73%** of households in England, compared to the next most affordable heating system option, ASHP affordable to 39% of households.

For archetype 2, bioLPG boilers were found to be affordable to **68%** of households in England, compared to the next most affordable heating system option, ASHP, only being affordable to 27% of households.

For archetype 3, bioLPG boilers were found to be affordable to **74%** of households in England, compared to the next most affordable heating system option, a hybrid heat pump, being affordable to 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.[4]

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; three days for archetype 1, twelve days for archetype 2 and two 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 system, 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 English homes. This poses a challenge for the installation of certain larger heat pumps, and needs addressing to prevent malfunctions of other electrical appliances.[7]

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.[8] 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.[9]

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]: BEIS, Sub-national estimates of households not connected to the gas network (2019).

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

[3]: Number of households in England: https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/families/bulletins/familiesandhouseholds/2020

[4]: 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*.

[5]: Office for National Statistics: https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/bulletins/householddisposableincomeandinequality/financialyear2020

[6]: Office for National Statistics: https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/compendium/familyspending/2015/chapter2housingexpenditure

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

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

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

Appendix:

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

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

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

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

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

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

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

Appendix

Capital Costs:

Heating System:	**Cost:**
Oil Condensing Boiler 12 kW	£2,100[10]
Oil Condensing Boiler 13-24 kW	£2,700[10]
Oil Condensing Boiler 25-36 kW	£2,900[10]
Oil Tank	£1,250
Coal Boiler <25 kW	£251 /kW
Coal Boiler 25-50 kW	£174 /kW
Gas Condensing Boiler 12kW	£1,500[10]
Gas Condensing Boiler 13-15kW	£1,600[10]
Gas Condensing Boiler 16-18kW	£1,700[10]
Gas Condensing Boiler 19-24kW	£1,900[10]
Gas Condensing Boiler 25-28kW	£2,000[10]
LPG Tank Rental	*£65 / year*[11]
Biomass Boiler 10kW and below	£8,120[12]
Biomass Boiler 11-15kW	£9,534[12]
Biomass Boiler 16-20kW	£11,544[12]
Biomass Boiler 21-25kW	£13,650[12]
Biomass Boiler 26-30kW	£18,100[12]
Hybrid Heat Pump <5kW	£1,285 / kW[13]
Hybrid Heat pump 5-11kW	£625 / kW[13]
Hybrid Boiler	£1,000[13]
Hybrid Installation Cost	£2,600[13]
ASHP 7kW (A1 + R)	£7,930[12]
ASHP 8kW (A1 / A3)	£8,270[12]
ASHP 10W (A3 + R)	£10,650[12]
ASHP 11kW (A2 + R)	£10,830[12]
ASHP 16kW (A2)	£13,060[12]

Fuel Price:

Heating Fuel:	Fuel Price[14]
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[10, 15]
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[16]
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