Evaluation of renewable and zero emissions heating systems in affordable housing projects

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Evaluation of renewable and zero emissions heating systems in affordable housing projects

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For the Scottish Government

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Table of contents

Notice

List of acronyms and abbreviations

ASHP	Air Source Heat Pump
Capex	Capital expenditure
DHN	District Heating Network
GSHP	Ground Source Heat Pump
kWh	kilowatt-hour
LZCGT	Low and Zero Carbon Generating Technology
LPG	Liquid Petroleum Gas
M&E	Mechanical and Electrical
RSL	Registered Social Landlord
SAP	Standard Assessment Procedure
Opex	Operational expenditure
O&M	Operation and maintenance
PV	Photovoltaic
VAT	Value Added Tax

List of definitions

Capex	For the purposes of this study, capital expenditure (capex) is defined as the equipment and installation costs of a heat and hot water generation and storage system.
District heat network	A district heat network is a communal heat system to which heat is provided by a single source, such as a biomass boiler or ground-source heat array, to multiple buildings via underground insulated hot water pipes.
Heat pump	A heat pump is a device that moves heat from an environment (atmospheric air, the ground, or a water source) and uses electricity to raise its temperature to provide space heating and hot water.
Heat battery	A heat battery is a thermal store that uses a phase-change (liquid to solid material) to store hot water.
LZCGT	A Low and Zero Carbon Generating Technology (LZCGT) is defined by the Scottish Government as one of the following technologies: wind turbines, water turbines, heat pumps (all varieties), solar thermal panels, photovoltaic panels, combined heat and power units (fired by low emission sources), fuel cells, biomass boilers/stoves and biogas.
SAP	The Standard Assessment Procedure (SAP) is a methodology implemented by the UK Government that uses information relating to the design of a home and climate and occupancy assumptions to determine if the energy and environmental performance of a new home meets building standards
Section 75	Under Section 75 of the Town and Country Planning (Scotland) Act 1997, a large housing development may be obligated to include affordable housing in order to receive planning permission. Therefore, the affordable housing portion of the development is sometimes referred to as its 'Section 75 requirement'.
Opex	For the purposes of this study, operational expenditure (opex) is defined as the fuel or electricity costs associated with running a heating system (and excludes maintenance costs).

1. Executive summary

In response to the global climate crisis, the Scottish Government has established a commitment to reach net zero greenhouse gas emissions by the year 2045. In contribution to this, the Scottish Government announced incoming legislation that will mean all new homes given planning consent from 2024 must use renewable and zero emissions heating systems. These heating systems will need to have zero direct emissions at point of use.

In November 2020, the Scottish Government appointed Locogen to deliver an evaluation of renewable and zero emissions heating systems in 21 recent or live Scottish affordable housing projects. The key objectives of this study were to:

- Assess the estimated, actual, and counterfactual costs of the projects' heating systems.
- Determine the drivers behind decision making for each project.
- Provide recommendations for further study in future evaluations.

1.1. Limitations to this study

There were several limitations to this study which are important to consider and caveat. These include:

- The sample size of projects was small and so caution should be taken when drawing conclusions from this research.
- The capital costs of heating systems displayed only include the procurement and installation of the heat generation and storage system and not the distribution system. In some cases, the costs are estimates and therefore are subject to change.
- This study only considers heating system capex and opex, which is defined as the running costs experienced by tenants. We believe it is important to also consider carbon emissions, building fabric capex and maintenance costs when making decisions on new build regulations.

1.2. Stakeholder interviews – key findings

The key findings from our RSL and Council stakeholder interviews on their experiences with Low and Zero Carbon Generating Technology (LZCGT) affordable homes projects are:

1. Meeting tenant needs, site characteristics, regulations, funding availability and sustainability ambitions are key motivating factors for RSLs and councils to use LZCGTs.
2. The expertise and motivations of internal and external decision makers and stakeholders strongly influenced the decision-making process in projects.
3. Capex is one of the main influences on heating system choice, with LZCGT heating systems found to be an expensive aspect of total costs when compared with non-LZCGTs.
4. Most stakeholders were not concerned about LZCGTs impacting electricity network costs, due to these being considered at an earlier stage in the project or by other stakeholders.
5. Rural and hard-to-reach areas are experiencing higher costs and a local skills gap, but otherwise supply chain issues were not being experienced for LZCGTs.
6. There is a gap on monitoring new LZCGTs, which could provide important evidence on real-world running costs.

1.3. Cost data – key findings

The key findings from our project cost data analysis are:

1. LZCGTs are £2,000 to £5,000 more expensive per unit than the default on-gas option, this being gas boilers with solar PV (as gas-based new build homes in Scotland are required to have renewables). For off-gas systems, there is no real default non-LZCGT option, so these projects are more likely to opt for LZCGTs than on-gas projects.
2. There is a vast range in capex, even for the same technologies (particularly ASHPs), but less variation within projects across various unit sizes. Shared systems, including DHNs, are more expensive than individual ones.
3. As per Table 1, LZCGT equipment and installation capex ranges from £5,000 per unit (individual ASHPs in large rural project) to £11,500 per unit (GSHPs in large rural project).
4. Of the technologies considered, GSHPs have the lowest operational cost, followed by ASHPs, then Solar-PV based systems. Due to the standing charge for gas, gas boiler systems are more expensive to operate than any of the LZCGTs considered (aside from biomass DHNs, which aimed to be cost-competitive with gas).
5. Due to the limited data for most LZCGTs and high variation in the projects themselves (sustainability levels, locations, sizes, unit types, procurement process), trends and programme-averaged values are presented with low confidence and are highly caveated.

	LZCGT	Gas counterfactual	Off-gas counterfactuals
Capex range	£5,000 - £11,500	£3,000 - £6,500	£4,400 - £11,800
1-bed opex	£121 - £216	£216	£274 - £433
4-bed opex	£199 - £294	£294	£409 - £710

Table 1: Summary of LZCGT costs vs counterfactuals

1.4. Recommendations

Based on our research, we propose the following actions to inform the development of the 2024 standards and ultimately increase the uptake of LZCGTs in affordable homes.

Investigation	1. Consider the costs of higher-specification building fabric for all sustainability standards. 2. Further investigate the cost difference between sustainable homes standards, comparing like-for-like projects and costing new future requirements. 3. Analyse real-world running cost data for LZCGTs and compare to SAP estimates and the carbon-intensive counterfactuals. 4. Survey tenants to determine their comfort levels and overall satisfaction with their LZCGT systems

Intervention	1. Continue affordable homes funding and Greener standard premium and add a LZCGT premium to support additional cost. 2. Make cost breakdown reporting a standard requirement for affordable homes funding. 3. Facilitate best practice and knowledge sharing between LAs, RSLs and developers to support a higher take up of LZCGTs. 4. Look into how to upgrade SAP to better specify LZCGTs, predict running costs more accurately, and include a wider variety of LZCGTs.
Innovation	1. Create a rural skills consortium to support rural developments. 2. Support innovative business models that might lead to subsidy-free affordable, sustainable, and net-zero homes in the future. 3. Create price transparency on LZCGTs capex and opex to drive market growth. 4. Encourage energy suppliers to offer more attractive electricity tariffs for LZCGTs.

2. Introduction

2.1. This report

In November 2020, the Scottish Government appointed Locogen to complete an evaluation of renewable and zero emissions heating systems in 21 Scottish affordable housing projects. This report is the key deliverable of that study and its aims are:

- to assess the estimated, actual, and counterfactual costs of the participating projects' heating systems
- to determine the drivers behind decision making for each project
- to provide recommendations for further study in future evaluations.

To do this, Locogen contacted representatives from seven Local Authorities (Councils) and eight Registered Social Landlords (RSLs) who had recently developed one or more affordable housing projects or were currently doing so.

The scope of this study is divided into three work packages. Our methodology for each of these work packages is explained in Section 3, and an overview and characterisation of the participating projects is provided in Section 4. The remaining body of the report summarises the findings made across the three work packages.

2.2. Policy context

In response to the global climate crisis, the Scottish Government has established a commitment to reach net zero greenhouse gas emissions by 2045. In contribution to this, the Scottish Government announced incoming legislation that will mean all new homes given planning consent from 2024 must use renewable and zero-emissions heating systems. These heating systems will need to have zero direct emissions at point of use.

Changes to domestic building standards will affect many stakeholders within the new build housing sector, including private developers, Councils and RSLs. The latter two organisations are the primary recipients of funding to deliver affordable homes with the support of capital grant funding through the Scottish Government's Affordable Housing Supply Programme. The Scottish Government committed more than £3.5 billion to deliver 50,000 affordable homes over the financial years 2016-17 to 2020-21, with the undernoted grant subsidy benchmarks determining the appraisal route that a Council's or RSL's application for grant funding follows:

	West Highland, Island authorities and remote/ rural Argyll	**Other rural**	**City and urban**
RSL social rent – greener	£84,000 (3 person equivalent, benchmark per unit)	£74,000 (3 person equivalent, benchmark per unit)	£72,000 (3 person equivalent, benchmark per unit)
RSL social rent – other	£82,000 (3 person equivalent, benchmark per unit)	£72,000 (3 person equivalent, benchmark per unit)	£70,000 (3 person equivalent, benchmark per unit)

RSL mid-market rent – greener	£46,000 (3 person equivalent, benchmark per unit)
RSL mid-market rent – other	£44,000 (3 person equivalent, benchmark per unit)
Council social rent – greener	£59,000 (flat rate benchmark for council projects per unit)
Council social rent – other	£57,000 (flat rate benchmark for council projects per unit)

Table 2: Affordable Housing Supply Programme grant subsidy benchmarks (as of January 2021)

As Table 2 demonstrates, higher grant subsidy benchmarks are available to RSL social rent projects in rural and remote locations, where it is known and accepted that costs are generally higher due to location. An additional benchmark of £2,000 is available for Council and RSL projects meeting the greener standard. This standard relates to the sustainability standards in Section 7 of the current Scottish Domestic Building Standards Technical Handbook and is defined as Bronze Level plus Aspect 2 of Silver Level. These sustainability standards are summarised in the following table.

Standard	Description
Bronze	Meets the functional standards set out in Sections 1 to 6 of the 2019 Building Regulations.
Bronze Active	Meets the Bronze standard (as above) and uses a Low and Zero Carbon Generating Technology (LZCGT).
Silver	Meets Bronze standard plus 8 additional 'Aspects' of sustainability.
Silver Active	Meets the Silver standard (as above) and uses a Low and Zero Carbon Generating Technology (LZCGT).
Gold	Meets Bronze standard plus 8 additional 'Aspects' of sustainability, which are more arduous than those at Silver Level.
Platinum	Meets Gold standard and has Dwelling Emission Rate (DER) of zero.

Table 2: Sustainability Standards under Scottish Building Regulations

For the Silver and Gold standards, Aspects 1 and 2 are most relevant to this evaluation as they relate to energy and emissions. These are defined as follows in the 2020 Domestic Building Standards Technical Handbook:

Aspect Silver level 1: Carbon dioxide emissions

All new dwellings that meet or exceed the Target Emissions Rate (TER) detailed in Section 6, Energy, of this Handbook, will automatically meet the Silver level criteria in respect of CO_2 emissions. This is due to the 21% improvement on the 2010 standards that occurred in October 2015.

Aspect Gold level 1: Carbon dioxide emissions

Under the guidance to Standard 6.1, the carbon dioxide emissions (Dwelling Emission Rate) are to be 27% lower than the Target Emission Rate set by the 2015 Standards. Where a building contains more than one dwelling (such as a block of flats or terrace of houses), the average carbon dioxide emissions for the proposed block or terrace (DER) may be compared to the average target CO_2 emissions (TER) for the 'notional block or terrace'.

Aspect Silver level 2: Energy for space heating

Maximum annual demand for useful energy for space heating should be: 40kWh/m^2 for houses, or 30kWh/m^2 for flats or maisonettes. To assess, the output from box no.99 of the SAP 2012 DER worksheet should be no more than the figures above.

Aspect Gold level 2: Energy for space heating

Maximum annual demand for useful energy for space heating should be: 30kWh/m^2 for houses, or 20kWh/m^2 for flats or maisonettes. To assess, the output from box no.99 of the SAP 2012 DER worksheet should be no more than the figures above.

To demonstrate compliance with these Aspects, the Standard Assessment Procedure (SAP) must be used. SAP is a methodology implemented by the UK Government that uses information on the building design, and climate and occupancy assumptions, to determine if the energy and environmental performance of a new home meets building standards. SAP calculations are fundamental to the design of any new home in the UK and are a strong influence on several design factors including building fabric efficiency and heating system specification.

For example, in order to meet Bronze Level plus Aspect Silver level 2, which is the requirement for the greener subsidy benchmark in the Affordable Housing Supply Programme, the building fabric efficiency (i.e. the level of insulation) would have to be improved above levels that meet the Bronze criteria in order to achieve the desired annual space heating requirement per unit floor area. This is the output from box no.99 of the SAP 2012 DER worksheet referred to in the definitions. It is important to note, given the focus of this study, that meeting this Aspect is influenced primarily by the building fabric specified and not by the chosen heating system. Conversely, Aspect 1 of Silver or Gold level would be heavily influenced by the chosen heating system and its associated emissions – however, this is not a requirement of the Affordable Housing Supply Programme's current greener subsidy benchmark.

In summary, guidance on the operation of the Affordable Housing Supply Programme is a key influence on the design decisions and costs associated with delivering affordable housing in Scotland. The lack of uniformity of the heating systems across the projects participating in the study infers that Councils and RSLs are influenced by many other factors too. The main body of this report seeks to identify, explain and analyse these other factors, to provide the Scottish Government with a greater understanding of current heating system specification in affordable housing, as well as the future challenges that may be anticipated as Scottish building regulations are adapted, to further align with decarbonisation legislation.

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3. Methodology

3.1. Overview

The scope of our research and this report consists of three work packages, as summarised in the overview diagram in Figure 1, which was devised by the Scottish Government. The detailed methodology for the three work packages is detailed in Section 3.2 and the rest of this report summarises our findings. For ease of understanding, work package 2 has been presented first as this ordering allows for the findings from work package 1 to be better understood.

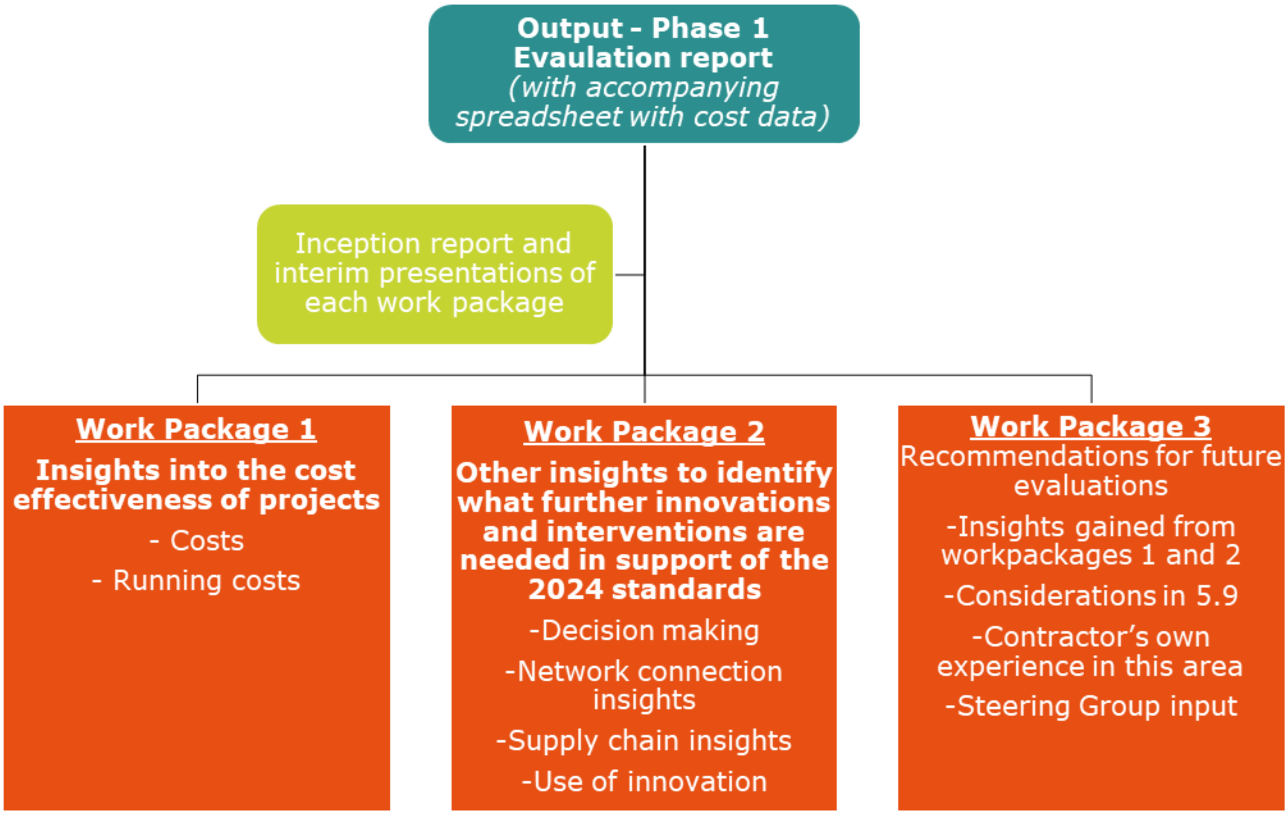

Figure 1: Overview of evaluation scope

3.2. Detailed Methodology

3.2.1. Work package 1

Work package 1 focussed on collecting cost information from each of the affordable housing projects that participated in the study. The following information was requested from each project:

- Estimated and actual capital cost breakdowns for heating systems
- Estimated comparative capital costs for counterfactual carbon-intensive systems
- Network costs associated with the heating systems
- Heat and hot water demand and annual costs for chosen and counterfactual systems.

Of the 21 projects, 15 were at a sufficient stage of development to provide at least some of this information, and all but two of these shared cost and/or energy demand data. This information was collated for each project and for each heating system technology. Using programme-averaged values, heating system operational and running costs were characterised for four occupancy-based housing archetypes.

3.2.2. Work package 2

Work package 2 involved remote interviews with the representatives of each project to understand the decision-making process that led to the chosen heating systems, as well as the stakeholders' perceptions across several themes, including:

- Choice of technology
- User impacts
- Supply chain interaction
- Innovation

We also conducted interviews with the supply chain to determine their capacity to deliver zero-carbon heating to affordable housing projects. Interviews were held via Microsoft Teams, lasting 30 minutes to an hour. A discussion guide was developed and adhered to in order to ensure continuity of the themes covered in each discussion, whilst allowing for stakeholders to focus on topics that they considered important.

The project stakeholder interviews focussed on identifying the experiences and views of Councils and RSLs on:

- Motivations for low carbon heating
- The decision-making process
- Technology costs
- Network connection issues and costs
- Challenges faced for low carbon heating systems
- Supply chain capacity and capability to deliver
- Plans for monitoring the installations

The supply chain stakeholder interviews focussed on identifying the experiences and views of low carbon technology providers on:

- Barriers to housing developers on choosing low carbon technologies
- Key challenges they face
- Supply chain capacity and capability to deliver
- Critical points in the supply chain
- Products and services offered to housing developers

Lastly, we also met remotely with consultants from Riccardo Energy & Environment and Ramboll in order to ensure cohesion between the findings of this evaluation and their complementary studies for the Scottish Government.

3.2.3. Work package 3

Work package 3 centred on analysing the findings from the two preceding work packages, in order to highlight the most important findings and areas where further study or action is recommended. Locogen has provided rationale and suggested methodologies for recommended areas of investigation, intervention and innovation, to be included in future evaluations.

4. Overview of affordable housing projects

An overview of the projects participating in the evaluation is presented in Table 3. The table shows their locations by local authority area; the type of heating system; the target sustainability standard; construction status and project size (the number of affordable housing units). Several technologies are abbreviated here and throughout the report, with GSHP, ASHP and MVHR denoting Ground Source Heat Pumps, Air Source Heat Pumps and Mechanical Ventilation with Heat Recovery, respectively.

#	Local Authority Area	Heating system	Sustainability Target	Status	Size
1	North Ayrshire	Solar PV & Electric boilers	Bronze + Silver aspects	On site	34
2	North Ayrshire	Solar PV & Electric boilers	Bronze + Silver aspects	On site	18
3	North Ayrshire	Solar PV & Heat battery	Silver + Gold aspects	Complete	4
4	North Lanarkshire	Solar PV & Heat battery	Gold	Complete	2
5	Perth & Kinross	ASHP	Bronze + Silver aspects	Pre-construction	4
6	Argyll & Bute	ASHP	Silver	On site	300
7	Angus	ASHP	SAP - 81	Complete	10
8	Scottish Borders	ASHP	Silver + Gold aspects	Pre-construction	4
9	Highland	ASHP	Bronze	Pre-construction	14
10	South Ayrshire	ASHP	Unconfirmed	Delayed	14
11	Perth & Kinross	ASHP	Unconfirmed	Delayed	50
12	Dundee City	ASHP & MVHR	Unconfirmed	Delayed	30
13	Highland	ASHP, Solar PV & Heat battery	Bronze + Silver aspects	Pre-construction	117
14	Glasgow City	ASHP, MVHR & Heat battery	Platinum	Complete	2
15	Dumfries & Galloway	ASHP, MVHR & solar thermal	Silver	On site	5
16	Scottish Borders	Shared ASHP	Silver + Gold aspects	Pre-construction	21
17	Edinburgh City	Shared ASHP	100% above Silver	Pre-construction	41
18	West Lothian	Shared GSHP	Silver	Pre-construction	16

19	Edinburgh City	Shared GSHP	Bronze + Silver aspects	On site	84
20	Fife	Shared Biomass	Bronze + Silver aspects	On site	85
21	North Ayrshire	Shared Biomass	Bronze + Silver aspects	On site	123

Table 3: Overview of projects included in this study.

Of the 21 projects initially included in the evaluation scope, three were not able to participate due to delays. As such, we were not able to confirm all of the information for these projects, hence they are not referenced in any further sections of this report.

The project locations are shown below in Figure 2, where they are categorised according to the type of heating system. Where the category includes a '+' symbol, this indicates that there are several additional technologies included in the heating systems. The markers also give an indication of the size of each development (not to scale).

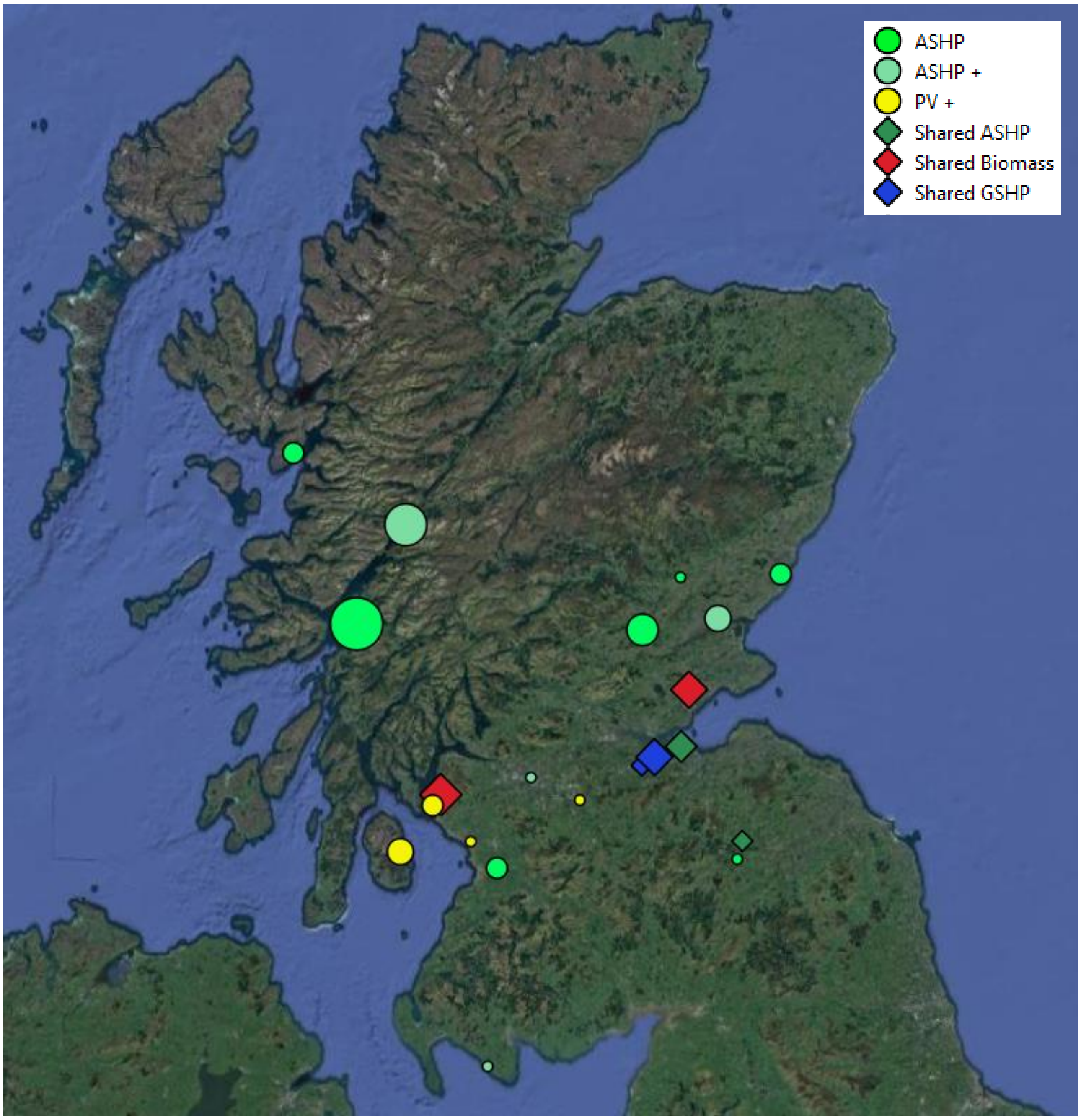

Figure 2: Project locations and heating system types

Figure 2 shows that the majorty of the projects participating in this evaluation are located close to or within the Central Belt of Scotland. There are also several remote, rural projects, including three located on Scottish islands.

Figure 3 demonstrates the split between settlement types according to the Scottish Government Urban Rural Classification, as well as the significant variation in project size. Whilst most projects have no more than 20 homes, there are a few with more than 100 homes, the largest having 300 homes. In Figure 3(c) projects are classified as 'large' if they comprise more than 20 affordable housing units. These factors have been presented here as they are likely influencers of a housing project's design, including its heating systems. The given distribution of size and settlement type indicates the variability in the sample and the potential broad range of factors that could impact heating technology choice.

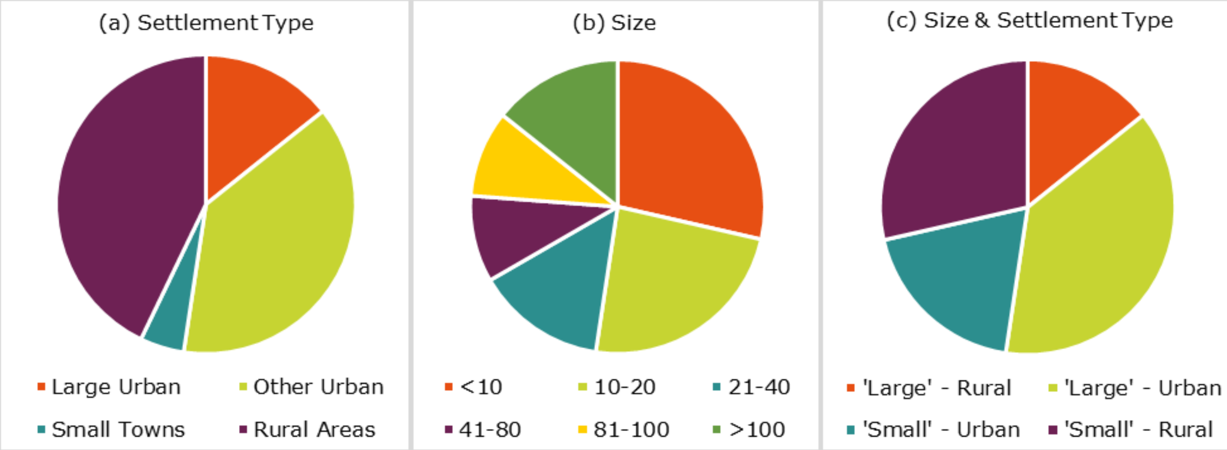

Figure 3: Size and settlement classifications

Figure 2 also indicates that there is a broad variation in the heating systems specified across the various projects. This is further demonstrated in Figure 4, which shows the chosen technology, fuel type and composition of the 21 heating systems across the original projects. Clearly, heat pumps are used across the majority of the projects, with indvidual ASHPs being the most common.

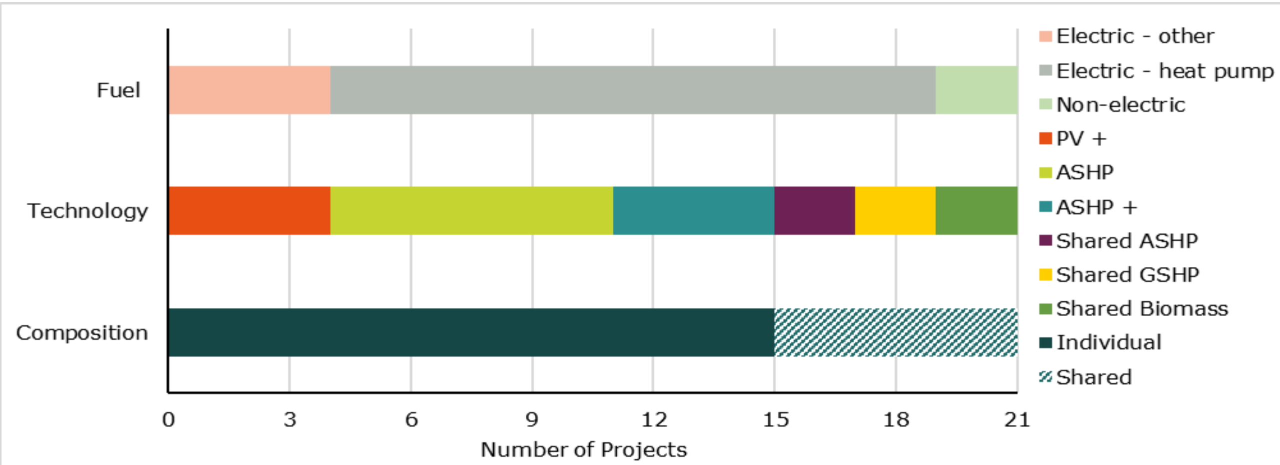

Figure 4: Heating system classifications

The projects are classified by what sustainability standard their energy systems are designed to achieve in Figure 5. The three delayed projects have not been included here as the targets were not confirmed and some of the other targets may be subject to change. The information provided indicates that the vast majority of the projects have heating systems that are designed to meet Silver Standard. Projects achieving Silver or a higher standard will meet the Affordable Housing Supply Programme's greener standard.

The two projects denoted as 'Higher' in Figure 5 include one Platinum project (which is notably the only project in this study to employ hybrid gas boiler air-source heat pump systems) and another which was yet to select a sustainability standard but aimed to be "100% improved versus Silver standard". The project listed as 'Other' was devised before the standards became mandatory, but (based on the target SAP score of 81 for the homes) would likely achieve Silver standard for its heating systems. The single 'Bronze' project was not able to afford Silver standard within the project budget.

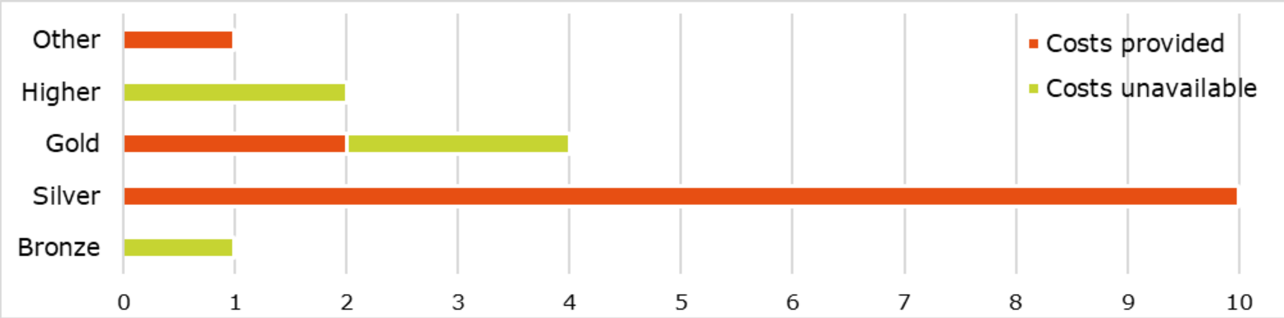

Figure 5: Standards specified for heating system aspects of the Scottish building regulations' sustainability levels

The Bronze and Platinum projects were not able to provide cost breakdowns for their heating systems for work package 1 of this study. The other project aiming to meet a 'Higher' standard than Gold had not designed its heating systems yet and therefore had not yet costed this. The cost data presented in subsequent sections of this report relates only to projects that meet Gold and Silver (or equivalent) sustainability standards.

5. Stakeholder interview findings

In this section, findings from the 14 stakeholder interviews representing 18 projects are summarised according to key themes, including: motivations for adopting LZCGTs; the decision-making process to arrive at a given LZCGT heating system; challenges associated with these new technologies; and insights on monitoring these systems.

Supply chain insights are also presented, which have been further informed by discussions with several LZCGT suppliers. Given the many variations between project aims, scales, locations, among other factors, the findings (and the associated tables and figures) are generalised, although important deviations and nuances have been highlighted.

5.1. Chapter summary

The key findings from RSL and Council stakeholder interviews on their LZCGTs experiences are:

Motivations	Meeting tenant needs, site characteristics, regulations and funding availability were deemed as the top four motivating factors for why RSLs and Councils are using LZCGTs. Climate change and sustainability ambitions were very strong fundamental factors too, with various strategies and ambitions to achieve standards above the baseline as the norm.
Decision making	The expertise and motivations of internal and external decision makers and stakeholders strongly influenced the decision-making process in projects. Capex was one of the main influences on heating system choice, with LZCGT heating systems found to be an expensive aspect of total costs, compared to ‘traditional’ systems. RSLs balance out the available grant with private finance, and there is a gap in meeting higher than Silver Aspect 1 and 2 standard.
Building fabric	The building fabric specification was the key decider of whether a project qualified for the Affordable Housing Supply Programme’s greener subsidy benchmark. A few stakeholders suggested that this cost an additional £6,000 to £9,000 per unit. Fabric and technology choice are interconnected through SAP, of which there were many grievances on its assumptions and inaccuracies.
Network costs	Most stakeholders were not concerned about LZCGTs impacting electricity network costs, due to these costs being considered at a much earlier stage in the project (e.g. site acquisition) and sometimes by other stakeholders. If network upgrades were required, these were perceived as a norm for new build sites.
Supply chain	The majority of stakeholders experienced no issues with the supply chain or felt that the supply chain issues were not a major problem for LZCGTs. The exception to this was stakeholders in rural and hard-to-reach areas who were experiencing higher costs and a local skill gap - an issue for construction and ongoing maintenance of LZCGTs.

Challenges to LZCGTs	There is a long list of challenges to LZCGTs that vary depending on stakeholder, site and technology type, but there was a clear top three with the additional cost of LZCGTs over default options being the biggest challenge. Tenant affordability and usability were also identified as key challenges.
Monitoring	There is a gap on monitoring LZCGTs, which could provide important evidence on real-world running costs. Monitoring was identified primarily in communal or district heating systems where it is required for billing and metering. All stakeholders recognised the benefits of monitoring, but a lack of funds was highlighted as the main reason for not establishing a monitoring program.

5.2. Motivations

There are a variety of drivers for why RSLs and Councils are using LZCGTs, as outlined in Table 4, but the stated primary key drivers were:

1. Tenant needs
2. Site characteristics
3. Meeting regulations
4. Funding availability

Despite corporate strategy, climate change ambitions and other ‘softer’ factors that were mentioned frequently (and scored highly in Table 4 below), the four factors above were identified as the key underlying motivators for incorporating LZCGTs into new build projects. Of primary importance to most stakeholders was the need for their developments to address fuel poverty and be affordable for future tenants, as well as any other additional tenant requirements, such as care needs. Site characteristics, in some cases, provided the motivation to consider LZCGTs due to these being the only technologies that would be viable. For example, LZCGTs were considered if a site was in an off-gas location where the default gas boiler option was not available, if the site was being developed near to an existing heat network, and if a later phase of a project was designed to replicate an earlier phase.

‘[The council] declared a climate emergency … so low carbon technologies are always on the agenda as something we need to look at.’

Using LZCGTs to meet building regulations including sustainability aspects (albeit to higher standards) was a key motivator and led to LZCGTs needing to be used over default options (e.g. gas boiler on-gas and electric storage heaters off-gas). Funding availability was rated highly due to all stakeholders needing the funding to make the projects happen. However, the general rhetoric was that it was less of a driving force and more of a necessity to enable LZCGTs to be installed in new builds, due to the cost disparity over the default options.

‘With the new regulations for new builds coming in 2024… [the board] took the decision that any new place would have ASHPS.’

Across all RSLs and Councils interviewed, climate change and sustainability ambitions are clearly very strong. All stakeholders discussed various internal strategies to meet their own, city-wide or Government climate goals. Moreover, all stakeholders aim to (and in most cases are) achieve standards above the baseline and are well known to be ahead of private developers in terms of LZCGT adoption.

‘The grant is not a driver, but nice, welcome support.’

Having the right stakeholders present was an important factor, but not always stated, or experienced by all projects (perhaps due to the lack of these types of stakeholders). Those with the right external ‘hand holders’ and internal champions tended to be more motivated by LZCGT and have fewer issues throughout. Hand holders included, for example, LZCGT manufacturers, solution providers, and external consultants, including energy, architects, or engineers (discussed more in section 5.3.1). Often these stakeholders would be involved upfront and throughout the projects.

‘We’ve been using ASHPS since 2011.’

Ongoing Operation and Maintenance (O&M) burdens and having an interest in LZCGT were influencers rather than driving forces. How O&M factors were considered varied (explained in more detail in section 5.3.4) and in some cases posed challenges too (see section 5.5). Similar to having the right stakeholders present, having stakeholders with an interest in LZCGTs led to internal ‘champions’, which influenced LZCGT selection.

Driver	Description	Strength of Driver
Climate Change	Overarching net zero, sustainability and climate change drivers.	■■■
Experience of LZCGT	Previous experience of installing and operating LZCGT in homes.	■■■
Tenant needs	Consider affordability and future tenants’ requirements e.g., care needs.	■■■
Interest in LZCGT	An interest in using low carbon technologies and materials.	■□□
Site characteristics	Specific requirements of the site e.g., off-gas, already part of heat network, only viable option.	■■■
Ongoing O&M	Consideration for the lifetime of the technology and associated running costs.	■□□
Innovation opportunity	Innovation trial, demonstration project, or presented with an opportunity to learn about LZCGT.	■■■
Funding availability	Availability of grants from e.g., Affordable Housing Supply Programme or Low Carbon Infrastructure Transition Programme.	■■■
Stakeholder influencers	Having the right stakeholders present, both external and internal, e.g., energy teams and suppliers involved before project commences.	■■□
Meeting Regulations	Using low carbon technologies to meet building or planning requirements.	■■■
Company strategy	Company strategy to e.g., achieve higher sustainability standards, reduce their long-term maintenance burden, meet anticipated regulation changes, upgrade business model.	■■□

Table 4: Motivation for RSLs and Councils to consider LZCGT adoption. Subjective score based on qualitative assessment of stakeholder interviews. Scored based on frequency of statement, explicit ‘key driver’ statements and subjectively weighted based on tone of conversation to attain ‘high’, ‘medium’, ‘low’ rating.

5.3. Decision making for heating systems

5.3.1. Decision makers

The expertise of internal decision makers and the motivations of external stakeholders were noted to strongly influence the decision-making process in each project. All of the roles identified through the interview process are listed in the table below.

Category	Role	Position	Involvement	Responsibility
Strategy & Management	Board	Internal	Sometimes	To define the strategy and approve the project team's decisions
	Project Manager	Either	Sometimes	To ensure that the project runs to schedule and to budget and coordinate between design team and contractors, and sometimes to manage procurement during the construction phase
	Housing Team	Internal	Always	To procure a housing development that meets the needs of tenants and the goals of the organisation
	Quantity Surveyor	External	Sometimes	To provide a cost estimate for the project and cost control during construction
Design	Architect	Either	Always	To architecturally design the development and coordinate Civil and M&E engineering design
	Civil Engineer	External	Always	To structurally design the buildings and design civil building services
	Mechanical & Electrical Engineer	External	Always	To design the development's mechanical and electrical building services, including energy systems
Design & Advice	Suppliers	External	Always	To advise on and design heating systems
Advice	Energy/ Sustainability Team	Internal	Sometimes	To ensure that the development meets sustainability goals and to advise on energy systems
	Mechanical & Electrical Consultant	External	Sometimes	To advise on the feasibility and impacts of energy system options

Category	Role	Position	Involvement	Responsibility
	Maintenance Team	Either	Sometimes	To confirm that the chosen heating systems can be maintained
Delivery	Developer	External	Sometimes	To design and build affordable housing as a Section 75 requirement for a larger development
	Main contractor	External	Sometimes	To manage procurement for the construction phase, and sometimes to design and build the project

Table 5: Roles and responsibilities for heating system decisions in affordable housing developments

Among the project teams interviewed, none had the exact same structure, although most Council projects were led by a housing team and were advised on heating systems by internal energy and/or sustainability teams. Some took on external advice from Quantity Surveyors and Mechanical & Electrical (M&E) Consultants to define and compare options. Suppliers' advice was also taken once systems were chosen. RSLs were more likely to require decisions to be approved by a Board and to have an internal Project Manager.

Taking advice from external consultants was generally perceived as very beneficial in terms of decision-making for heating systems. However, a few drawbacks were noted, namely that their reports create a lot of jargon and were not usually accessible to a lay person.

Of the projects participating in this study, each team's structure was very dependent on the type of development process, with the three key categories being:

- **Internally-led** – Design and procurement managed by RSL/Council team. Sometimes an external project manager is appointed to lead the development.
- **Design and Build (D&B)** – Contractor appointed to design and build the development.
- **Developer-led** – Housing developer approaches RSL offering to design and build affordable homes as a Section 75 requirement for larger development.

In the latter two cases, the developer or contractor will be given a budget and brief to follow by the internal housing team, who is allowed to have the final say on the project's heating systems.

5.3.2. Process

Along the pathway towards developing an affordable housing project, several strategic and design decisions influence the heating system options before these are considered in detail. A generalised decision timeline for an internally led project is provided in Figure 6. The timeline shows the key factors at several stages of development that can open or narrow the options for LZCGTs.

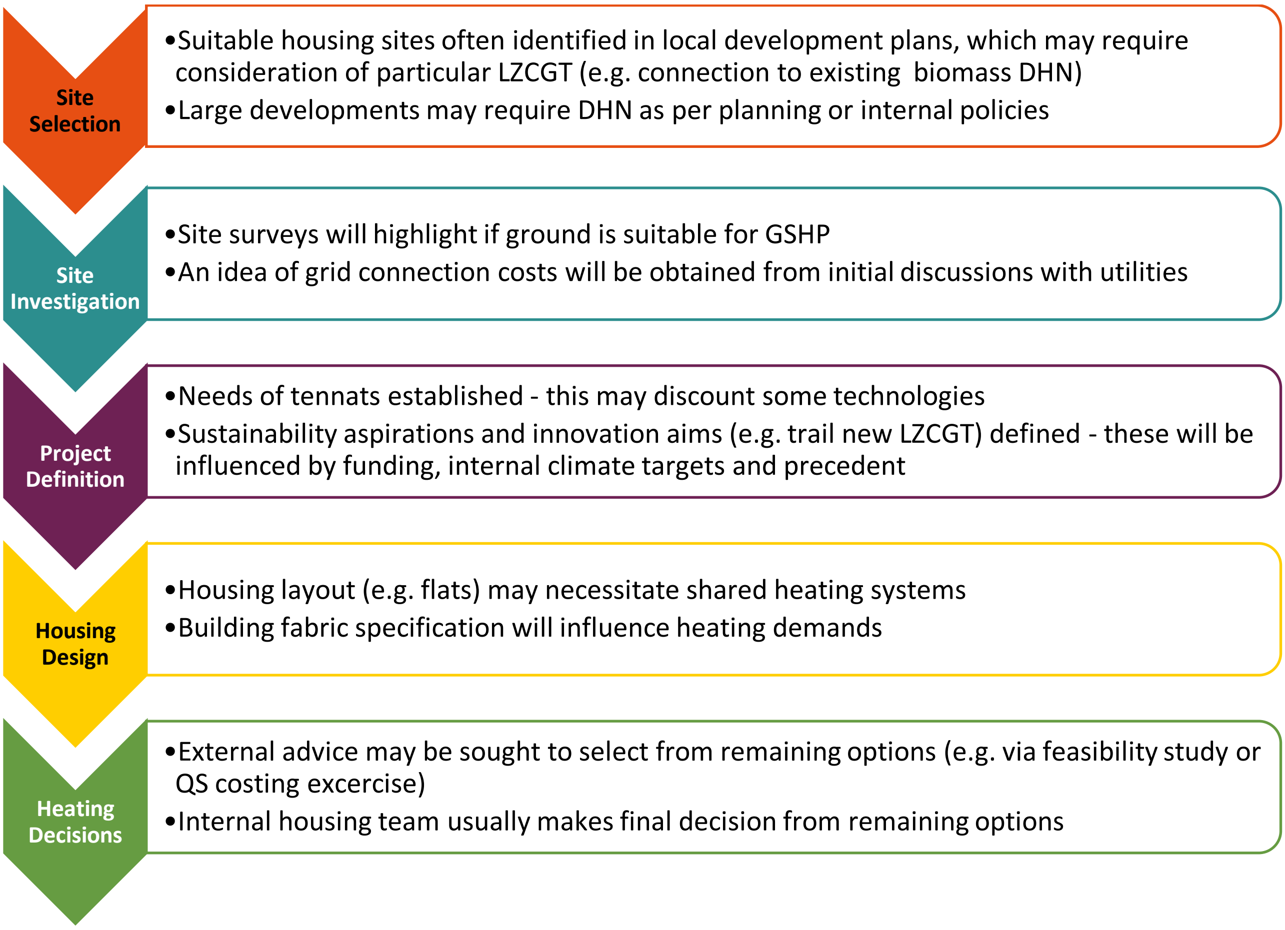

Figure 6: Illustration factors influencing heating system options

For Design and Build contracts, the Council or RSL will perform the first three stages before appointing a contractor, who must meet the design brief at a negotiated or competitive cost, depending on the tendering process. The project brief will define the sustainability aspirations of the development and may specify a particular LZCGT or range of options for heating systems. For developer-led contracts, an RSL will be approached by a developer, who will have already identified and investigated a site, and will agree to follow the RSL's decision brief. In this case, there is usually the option to choose the same heating system as the main development, but these are more likely to be built to lower sustainability standards than the affordable housing brief necessitates, meaning that gas and other fossil fuel systems are more likely to be specified by developers.

An issue highlighted with the timeline in Figure 6 by one project stakeholder is that the Housing Design stage can 'go too far' before heating systems are considered. If they were considered earlier on in the process, then other aspects of design, such as internal layouts, cupboard space and building fabric specifications, would not need to be revised to accommodate them. The stakeholder who raised this issue did note that it has generally been alleviating over time as more emphasis is placed on the environmental impact of housing developments.

5.3.3. Technology perceptions

In Table 6, perceptions of all heating and hot water systems discussed across the interviews are listed and categorised as reasons for and against their selection. As these are the perceptions of various organisations, some of the points listed may be contradictory. Similarly, the list itself is far from exhaustive as it captures only the points raised during discussions.

Technology	Reasons for selection	Reasons against selection
ASHP	Low capex; low opex; tried and tested in terms of design, installation, operation and/or maintenance; external unit accessible for maintenance	Noise concerns for external unit; concern for performance at costal locations; not as operationally efficient as GSHPs
ASHP (shared)	Best LZCGT option for flats where DHNs are not feasible	DHN feasible instead
GSHP	Few parts for tenants to interact with; low operational costs; low maintenance burden	High capex; ground not suitable; landscape not suitable (too hilly)
Heat battery	To trial a new technology; to meet higher sustainability standards	Perceived as unsuitable for larger properties; risk of new technology in isolated (island) location; only one manufacturer; perceived as incompatible with SAP
Solar PV	Enhanced SAP scores; reduced energy opex facilitated	High maintenance burden
Biomass DHN	To take advantage of existing Biomass DHN; to trial Biomass DHN; because a DHN was required	High capex; fuel availability and sustainability concerns; commercial VAT rates apply to domestic energy if RSL/Council-owned; too many parties required for development
Mechanical Ventilation with Heat Recovery	To facilitate higher levels of airtightness required to achieve better building fabric performance	Wary of tenant interaction with ventilation
Solar thermal water heating	To provide free water heating to comply with Aspect Silver level 3: Energy for water heating[1]	*None identified – incorporated only in one development*
Mains Gas	Low capex; low opex; tried and tested	High operating emissions; requires PV to pass SAP; non-compliance with incoming regulations; short operational life

[1] Within Section 7 of the Scottish non-domestic Building standards, Aspect Silver level 3 is met if 'at least 5% of the dwelling or domestic building's annual energy demand for water heating should be from: heat recovery and/or renewable sources with little or no associated fuel costs … that are allocated for water heating.'

LPG DHN	Low capex (compared to other DHN options); tried and tested;	High operating emissions; wary of low capex as a loss-leader for opex; wary of long-term supply contracts; requires PV to pass SAP
Electric storage heaters	Low capex; Simplicity for operation	High opex; limited suitable tariffs; requires PV to pass SAP

Table 6: Technology choice factors

Within this study, ASHPs were a clear favourite LZCGT for heating. This is because they are widely perceived as able to provide a balance between costs to the Council/RSL (capital and maintenance costs) and operational costs (paid by tenants). Also, unlike gas and electric storage systems, they also pass SAP without requiring solar PV. As such, they are increasingly viewed as a ‘go to’ option, and, accordingly, several Councils/RSLs have now established a favoured manufacturer and/or model. Interestingly, the three stakeholders that named favourites each named a different manufacturer (Mitsubishi, Vallaint and Daikin).

It was also evident that many organisations, mainly RSLs, still opt for mains gas systems where possible, unless for the purposes of trailing new technologies. However, a small number of RSLs have now completely dropped mains gas systems from consideration, in anticipation of the incoming updates to Scottish building standards. All of the Councils interviewed have declared a Climate Emergency and so they tended to have stricter sustainability policies that either prohibited gas systems from being considered, or mandated higher standards, such as Silver or Gold standard. For example, one council have declared that all new build homes must meet Gold standard, although it is still possible and permissible to achieve this with gas boilers.

5.3.4. Technology costs

‘As regulations tighten, it’s becoming harder and harder to square the circle between costs & regulations.’

Almost all stakeholders advised that it is difficult to meet building standards ‘affordably’, and that LZCGT heating systems themselves are an expensive aspect of total unit costs, particularly compared to traditional gas systems. Therefore, capex was one of the main influences on the choice of heating system for several projects, mainly those that incorporated ASHPs as a sole component. However, several projects were motivated by other factors more than technology capex, and some chose to trial new technologies at additional expense in order to ‘do something different’ (in this case choosing heat batteries), or to deliver the lowest operational cost system to their tenants (in this case choosing GSHPs).

Where multi-technology heating systems were specified, this was done in order to meet higher sustainability standards, including full Silver and Gold. In these cases, the desire to meet these standards outweighed the cost impacts. Similarly, technology costs were noted as the main reason for not pursuing standards higher than Aspects 1 and 2 of Silver level. Stakeholders from one project – which has ASHPs, heat batteries and PV – noted that it was only possible to include multiple technologies through grant funding from the Scottish Government’s Low Carbon Infrastructure Transition Programme.

Technology costs varied greatly between projects, as demonstrated in section 6.1. In general, as would be expected, larger projects benefitted from economies of scale, resulting in lower unit costs for heating systems. Several stakeholders of projects in rural and remote locations, noted that capex for heating systems and most other project costs were much higher. One stakeholder provided a rule of thumb that costs for rural locations tend to be 15% higher than in the Central Belt, and 40% higher for affordable housing projects located on Scottish islands.

5.3.5. Building fabric and SAP

Regarding the design process for affordable housing developments, many stakeholders explained that a 'fabric first approach' was adopted, with u-values (the quantitative indicator for heat loss through a building fabric material) specified by the project's architect at an early stage. Scottish building standards specify maximum allowable u-values in new build homes, which the stakeholders perceived to lead to low heat demands.

'Building standards are very high for energy efficiency now.'

The airtightness of a building (essentially a measure of how 'leaky' it is) is another factor affecting heat demand. Several projects were noted to adopt offsite construction methods to enhance airtightness, amongst other benefits such as less time on site and more standardisation. Four stakeholders made very similar statements relating to the escalating costs of building fabric as u-values and airtightness tended towards PassivHaus[2] standards. As such, there are perceived to be diminishing returns for improving fabric efficiency.

'[Building standards are] at a point of diminishing returns on energy efficiency … we want to be as good as possible before the exponential cost curve towards the passivhaus standard kicks in … it's more than 10-15% more expensive to do a passivhaus.'

The building fabric specification (u-vales and airtightness) was noted to be the key decider of whether a project qualified for the Affordable Housing Supply Programme's greener standard, as this is based on achieving Aspect 2 of Silver level, which caps the annual heating demand of a projects' housing units. One stakeholder noted that to meet the greener standard, an additional £6-7,000 per unit was required, with the majority of this cost being attributed to enhanced insulation. Similarly, one of the projects that met Aspect 2 of Gold level incurred an additional cost of £9,109 per unit for the enhanced insultation needed to reduce annual heat demand by a sufficient amount.

Overall, fabric efficiency seen as a standalone consideration, made earlier on by the project's architect, that doesn't greatly influence LZCGT choice. However, it was acknowledged that achieving good fabric efficiency can lower the capex required for heating systems, by lowering peak demands.

Although they are broadly considered independently, often by different members of a project team, fabric and technology choice are interconnected through SAP. One notable example of this came from a stakeholder who noted that when their project's ASHP specification was changed, they had to add ceiling insultation to some properties in order to achieve the same SAP scores and sustainability standards. This also infers that projects

[2] The PassivHaus approach is a design standard for new build homes, whereby the energy demand is minimised through specification of building fabric with very high u-values and airtightness.

are designed to *just* meet a given standard in order to do so most cost effectively, and that the higher the standard, or the more aspect levels achieved for a given standard, the more an affordable home will cost to build.

‘SAP and EPC calculations are well off compared to the actual, by a factor of 3.’

There were several grievances raised with SAP across the interviews. The two most common were that it penalises Scotland (particularly the north of the country) and certain LZCGTs due to the temperature and emissions assumptions it works on. Additionally, SAP is known to produce very inaccurate operational cost estimates, which form the basis of Energy Performance Certificate (EPC) costs. Despite this point being widely agreed, comparing SAP cost estimates is the most common approach to compare different energy efficiency approaches and technologies amongst Councils, RSLs and their consultants.

5.3.6. Network costs

‘We didn't consider network costs at the start. There were compelling reasons to take it forward without this step.’

For biomass and LPG DHNs, network costs are easily determined as they are the main component of capex for these systems. For heat pumps and solar PV-based heating systems, electricity network costs were not found to be a significant influence across the projects in this study. In fact, only one had considered costs – the project with 117 homes. During the development of this project, it was found that a new substation would be required to accommodate the start-up currents of the ASHPs. The new substation cost an additional £50,000, which would not have been afforded without the Low Carbon Infrastructure Transition Programme funding that the project received. For this project, the impact of the heating system choice on network costs was more visible since the technology changed from an LPG network to ASHPs at a later stage.

Aside from this example, stakeholders were not concerned about the chosen heating system impacting electricity network costs and generally had limited insight on these costs, due to early-stage investigations being carried out by another stakeholder (either internally or externally) or being looked into at a different phase in the project (e.g. site acquisition). For section 75 developments and design and build contractors, the network works are handled by the developer or contractor, meaning that the RSL is not exposed to these costs. Alternatively, the network costs would have been de-risked at the site acquisition phase by the RSL or contractor.

‘We tend to want most of the constraint issues and big costs assessed first.’

‘Risks and costs are with the developer … I don't think the connection is a problem or additional cost”

If network upgrades were needed, these were quite often perceived as a norm for new build sites and there were no experiences of surprisingly high network costs. Three RSLs had to build new substations, one of which was on-gas and the other off-gas. Another RSL had a decade of experience with installing ASHPs and noted that paying additional network costs is an issue for large or rural locations, but that, where a substation was required, the impact of electric heating was not guaranteed to be an influence over and above this. Another RSL confirmed that new primary substations are just as likely to be an additional cost to on-gas developments as well, especially on larger sites.

Those more experienced in LZCGTs and dealing with utilities suggested that the Distribution Network Operators are unwilling to investigate how much electricity a site can self-generate to reduce the network upgrade cost. If this changed, one RSL stated that they would be happy to consider batteries or other solutions that could facilitate reduced network capex.

The figure below summarises the interactions of each of the projects represented in this study with electricity network costs.

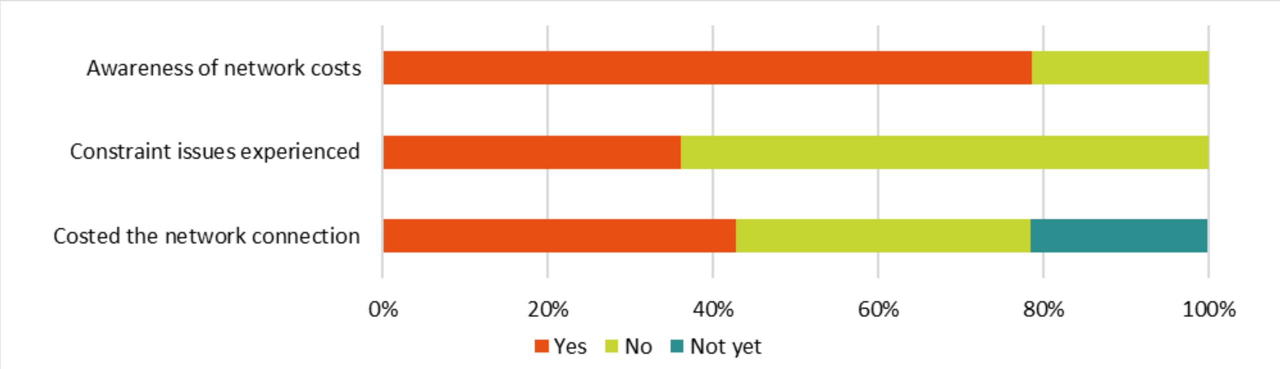

Figure 7: Electricity Network Connection Considerations

5.4. Supply chain insights

'There aren't any issues with the supply chain … I think it's just scare mongering.'

The majority of stakeholders interviewed either did not experience issues with the supply chain or felt that the supply chain issues were not a major problem. The only exception to this was due to location. Those who did experience issues with the supply chain can be directly correlated to location, i.e. the 36% answering 'yes' in Figure 8 were also located in rural and/or remote locations. The key issues experienced were:

- **Limited choices depending on what local skills are available.** Rural locations are often reliant on transporting in contractors from Scotland's Central Belt, some of whom are believed to be unwilling to do small/very small rural/remote projects. There is a limited pool of available contractors, they tend to be very busy, and may only be certified to install one brand/type of heat pump, for example. This limits the heating design options for the homes.
- **Not having readily available maintenance staff in the area**. Even if contractors are available for the build, stakeholders are concerned, or have experienced issues with getting the right and readily available maintenance expertise. One stakeholder suggested it would be cheaper to let their heating systems break down rather than procure a standard preventative maintenance regime (i.e. one-year servicing).
- **Procurement issues**. Specifically, having to use multiple sub-contractors from various locations, providing complicated and unsustainable project management.
- **Higher costs.** This is thought to be due to limited local competition or having to include contractor travelling costs. This is felt more at smaller sites. As mentioned in section 5.3.4, one stakeholder advised that costs for rural builds are 15% higher than in the Central Belt, and 40% higher for island projects.

This suggests that there is a clear issue with local, readily available and qualified resources in rural areas.

'An ASHP needs servicing once a year … getting contractors to rural areas where there aren't enough skills locally is an issue.'

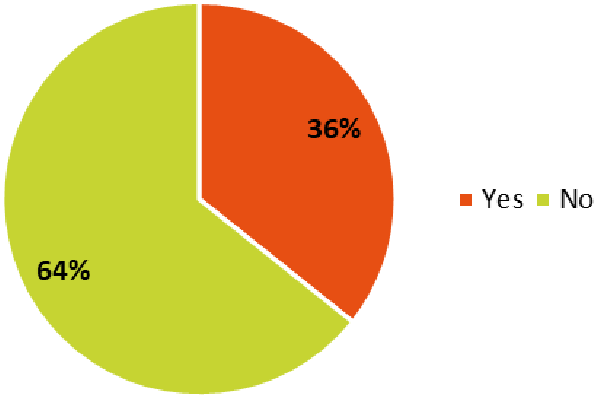

Figure 8: Responses to whether stakeholders experienced any issues with the LZCGT supply chain

In addition to location, the other supply chain issues (when they were experienced) were due to external factors and installers. Brexit and the COVID-19 pandemic were mentioned as factors that have impacted projects, this included rising costs, availability of materials (steel pipes and radiators) and limitations to travel. Whilst most stakeholders would state that manufacturers and installers are readily available, there were a few issues experienced with installers including perceived over-inflated prices, and the need to have multiple types or specialist contractors on site for installation and commissioning of certain technologies. There were less concerns on manufacturers, with only two stakeholders mentioning issues, including getting the equipment, and due to a worry over potential future issues due to using a start-up manufacturer (e.g. only one heat battery provider).

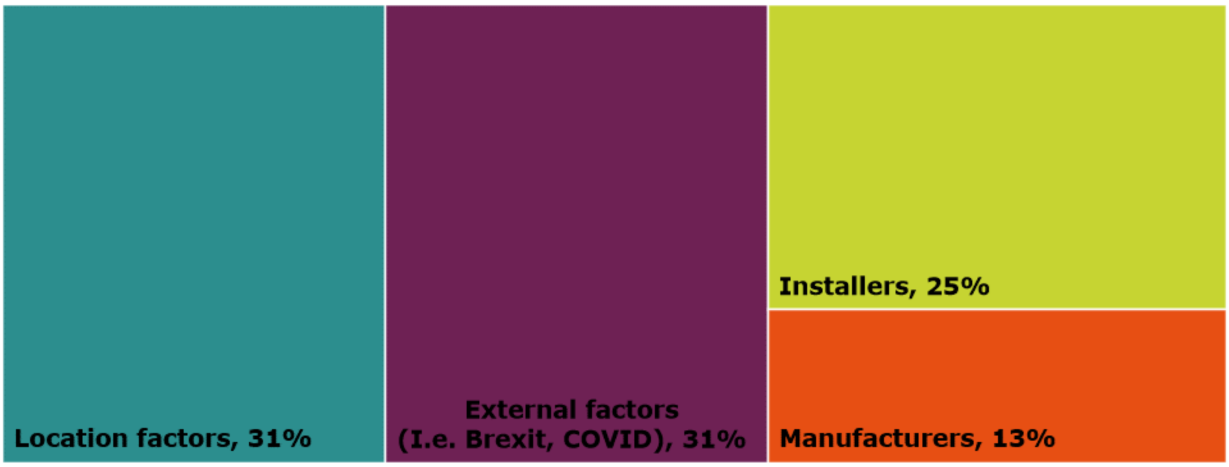

Figure 9: Supply chain issues experienced

5.4.1. Industry supply chain insights

Alongside RSL and Council interviews, we also interviewed a small number of industry stakeholders, including manufacturers and suppliers of low carbon technologies, to gain insight into what they think the key challenges to low carbon technologies are and whether supply chain constraints exist. These interviews were undertaken to help confirm or contradict the findings we were gathering from RSL and Council stakeholder interviews.

Key challenges to low carbon technologies

Across all the supply chain interviews, there were a number of common challenges to low carbon technologies that were stated and discussed, including:

- Lower carbon technologies having a higher capital cost compared with default solutions.
- SAP, which is a key issue and at a fundamental level penalises heat pumps over gas boilers.
- Lack of regulations forcing low carbon technologies in new buildings, and uncertainty in future regulations undermine investor confidence.
- Rumours of poorly installed heat pumps are believed to 'put people off'.
- Unlike RSLs, private housing developers do not consider opex, which would be a driving force for using low carbon technologies over the default options.

Critical points in the supply chain

Manufacturers do not see themselves as a critical point in the supply chain and there was consensus across the interviews that they have the capacity today (with high tens of thousands of products produced in the UK) and in the future to meet predicted increasing demand. All of the suppliers we talked to offered multiple products and services to housing developers, and RSLs and have had a lot of experience working with these types of companies, including 'hand-holding' for those who are newer to low carbon technologies.

There were some comments about installers being a key point in the supply chain. There was agreement between manufacturers that there are enough installers, but there appears to be an issue in how much installers are charging. One manufacturer explained that with increasing demand, you would expect prices to fall. However, installers appear to be charging the same or more with increasing demand for their services. It is unclear whether this is due to issues associated with high demand or installers simply 'getting away with charging more'.

5.5. Challenges with LZCGTs

Table 7 provides a summary of the challenge's stakeholders are experiencing with LZCGTs. There is a long list that varies depending on stakeholder, site and technology type, but there is a clear top three:

1. Additional cost
2. Tenant affordability
3. Tenant usability

The additional cost of LZCGTs over default options was the biggest challenge. A common suggestion throughout the interviews was that LZCGTs are more expensive. Section 6 discusses our findings on the cost of LZCGTs compared with the counterfactual for further insight on this. Whether tenants could afford and use them are the other top two challenges for LZCGTs. In terms of affordability, there were concerns from two perspectives. Firstly, to meet ever-increasing sustainability standards and to install LZCGT costs more, and this is inevitably going to be passed on to the tenants in higher rents. Secondly, there were some challenges around whether electric technologies were cheaper to run than gas. Some had experienced complaints from tenants on the cost of the system and plan to investigate tariffs further (i.e. energy suppliers not offering heat pump specific tariffs). There were also perceived and experienced issues with tenants not using LZCGT in the right way despite onboarding, leaflets and instructions being given. It was acknowledged that, fundamentally, the heating systems act in a different way to more familiar heating systems, with lower and enduring heat rather than high-output, boost heat, and tenants were not familiar with this type of heat supply. It seems that even with onboarding from the RSLs and the manufacturers, there are still some issues that need to be addressed.

Challenge	Description	Score
Additional costs	Extra capex costs to using LZCGT compared with default options.	
Tenant affordability	Running cost concerns e.g. how tenants might/do use them, lack of experience, availability of suitable tariffs.	
Tenant usability	Concerns over how user friendly the LZCGT is/will be.	
Billing and metering	An issue for communal or district heating systems.	
Operation and maintenance	Concerns and issues over how to, and the cost of, O&M for LZCGT.	
SAP	Restrictions inherent to SAP calculations and concern over accuracy of, for example, running costs.	
Suitability of LZCGT	LZCGT suitability depends on site characteristics and some options are not viable.	
Reliant on developer partners	RSLs may not be the decision maker on whether or not to use LZCGT due to, for example, private developer partners.	
Limited LZCGT options	Concerns over the limited options available for LZCGT	
Uncertainty over new technology	Uncertainty and/or lack of experience or evidence for LZCGT and how it may perform.	
Local residents challenge	Challenges from local residents to the development of using specific LZCGT, due to e.g. aesthetics, local pollution.	

Table 7: Challenges experienced with LZCGTs. A qualitative assessment of stakeholder interviews. The 'high', 'medium', 'low' rating is a based on the number of times the stated challenge was mentioned in stakeholder interviews.

The mid-rated concerns include billing and metering, O&M, and SAP. Finding new ways to deal with billing tenants was a challenge in communal and district heating systems projects. One RSL is upgrading their business model to become an Energy Services Company to deal with this (see Figure 15 in Section 7.4.3), others have identified partners to deliver this service. There were many complaints about SAP from a design and running cost perspective. Sometimes SAP calculations made it difficult to install the LZCGT of choice or added on cost. One stakeholder mentioned that they want to use infrared heaters, but these are not currently in SAP, and another RSL had a bit of a shock when they had to install PV in addition to Biomass Boilers to meet requirements. It is experienced and acknowledged across RSLs that the running costs are not accurate in SAP.

'It's a balancing act between grant income and private finance.'

Lower-level challenges are largely due to uncertainty over LZCGTs, but this was for specific technologies, or on less well used LZCGTs, e.g. district heating schemes and heat battery systems. The majority of stakeholders we spoke to had used LZCGTs. There were also a few project-specific issues like the challenges from local residents from one communal biomass boiler system.

5.6. Monitoring

Data monitoring

Nine of the projects in the evaluation include some kind of home energy monitoring program. The range of information collected varies widely and depends on the equipment installed. Among these projects, roughly half have communal systems or heat networks that inherently require heat meters to measure the energy flows into each property for billing purposes. Other projects are looking to monitor energy flows (heat and electricity demands and solar PV generation) as well as a broad range of other factors for internal or external research purposes. To do so, intelligent Internet of Things (IoT) sensors, connected to a LoWaRan network, are the most common approach among these projects[3]. Stakeholders advised that the following measurements would be collected:

- Air quality
- Carbon monoxide concentration
- Building fabric performance
- Internal natural light levels
- Internal humidity
- Internal temperature
- External temperature
- Weather

All stakeholders recognised the benefits of home energy monitoring, and a lack of funds was highlighted as the main reason for not establishing a monitoring program. Among those which do have a monitoring program, several motivations for it were identified, with contractual requirements being the two key drivers:

1. Requirement for billing for communal systems and heat networks
2. Requirement to share information with funders/researchers
3. To confirm that the heating systems work as anticipated and determine if they are useful for future projects
4. To share insights with other external bodies e.g. consultants
5. To troubleshoot tenants' problems e.g. high electricity bills
6. To link to Councils' wider energy programmes e.g. 'smart cities' activities

Aside from contractual obligations, monitoring was recognised as an important aspect of projects that have trialled new LZCGTs, as it allows for the performance of the technologies to be verified. Similarly, it allows for actual bills to be compared to estimates from SAP, which were noted by many to be highly inaccurate predictions. This is particularly important as SAP appears to be relied on more for LZCGTs than for more established heating systems, for which bills are more easily predicted.

'It's part of the feedback loop… we are hoping that everything will be successful but without monitoring it you're never going to know.'

The scale of a project was also noted to influence monitoring programs. For example, one council plans to monitor only one of each unit type, due to the large number of homes in

[3] The Internet of Things (IoT) refers to internet-connected devices that are able to exchange data with each other – for example, a phone connected to a smart thermostat which automatically controls a domestic heating system. LoRaWan® is a low power and wide area network protocol designed to enable wirelessly connecting 'things' to the internet.

the development. They suggested that they would be able to install further monitoring equipment in homes if tenants highlighted high bills, in order to identify and remedy any issue. Three projects that have a handful of homes with LZCGTs within a larger development plan to monitor these homes as well as the 'standard' home energy systems to compare heating systems within otherwise similar properties. An issue with small samples noted by one RSL was the impact of different household's structure and lifestyles – the interviewee worried that these differences would render the data collected hard to compare.

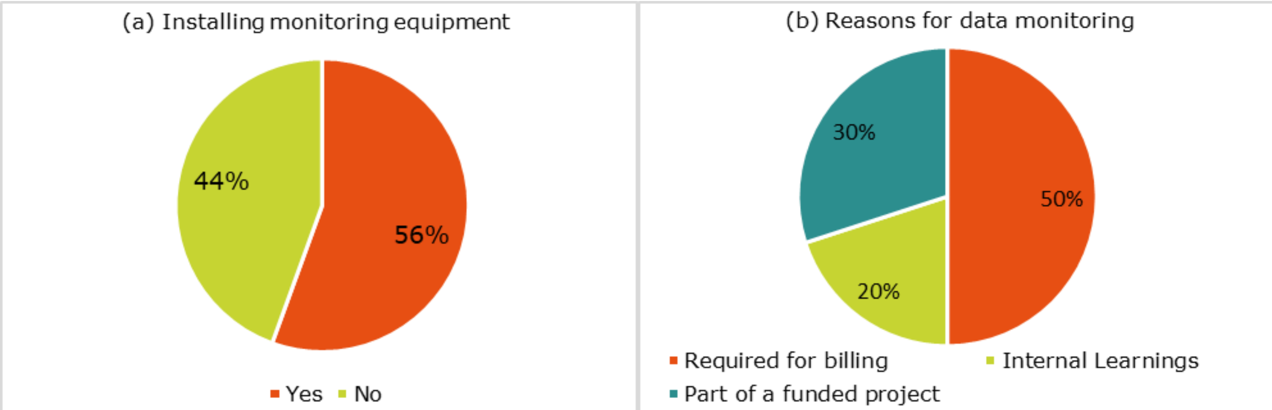

Figure 10: Projects installing monitoring equipment and reasons for doing so

Surveys and other tenant interactions

All Councils & RSLs interviewed plan to engage with tenants via post-occupancy surveys or have done so already. This appears to be a standard approach across the board, regardless of the heating system installed. A few also plan to use surveys as an analogue method for energy monitoring, through collecting information on energy consumption and electricity tariffs via tenants' bills in order to gain a better understanding of the affordability of heat pumps.

Several intend to take a more involved approach, including educating tenants on how to use their heating systems and, where ASHPs and/or heat batteries are installed, offering advice directly or via third parties on which electricity tariffs will secure cheaper energy bills. There was a general consensus that heat pumps are not inherently cheap to run and that they require the right electricity tariffs in order to be affordable to tenants, and that this advice was therefore necessary to ensure that the homes were affordable in all senses. Similarly, one Council plans to 'coach' tenants to switch to variable electricity tariffs, so that heat pumps and heat battery systems can be programmed to take in electricity from the grid at times when it is cheaper.

6. Low carbon heating system costs

In this section and in the associated Appendix B, the 13 projects for which cost data is available are grouped firstly by technology type, and then alphabetically. A summary of the data is presented first, followed by individual project data and then programme-averaged cost estimates for each technology and unit archetype, which have been inferred from the individual data.

Capex definition

Throughout this section and the associated appendices, capex (capital expenditure) is defined as the combined equipment and installation costs of the heat generation and storage system of a given affordable housing unit. Notably, this definition excludes heating distribution capex such as the costs installing underfloor heating or radiators.

6.1. Chapter summary

The key findings from our analysis of the projects LZCGT cost data are:

Capex	There is a vast range in capex, even for the same technologies (particularly ASHPs), but less variation within projects across unit sizes. Shared systems, including DHNs, are more expensive than individual ones. LZCGT equipment and installation capex ranges from £5,000 to £11,500 per unit. For counterfactual systems, capex ranges from £3,000 to £11,850.
Opex	GSHPs have the lowest operational cost, followed by ASHPs, then Solar-PV based systems. Due to the standing charge for gas, gas boiler systems are more expensive to operate than any of the LZCGTs considered (aside from biomass DHNs, which aimed to be cost-competitive with gas). Based on programme-averaged heat estimates, annual LZCGT opex costs ranged from £121 to £216 for one-bed homes and from £199 to £294 for four-bed homes. For counterfactual systems, opex ranged from £216 to 433 for one-bed homes and from £294 to £710 for four-bed homes
LZCGTs versus counterfactuals	Gas, LPG and direct electric heating systems generally require solar PV in order to pass SAP, so PV costs have been included within capex figures for these counterfactuals. LZCGTs cost around £2,000 to £5,000 more than gas boilers with PV. Data for off-gas counterfactuals was less conclusive, as few projects considered these because their high opex negatively impacts tenants.
Costing approach	Several Councils and RSLs did not cost counterfactual systems because other objectives or requirements narrowed down the choice of technologies. Most opex estimates were based on SAP calculations, which are broadly noted to be inaccurate predictions but useful to enable cost

	comparison between units, technologies and building fabric specifications.
Limitations of data	Due to the limited data collected for most LZCGTs (except ASHPs) and high variation in the projects themselves (sustainability levels, locations, sizes, unit types, procurement process), trends and programme-averaged values are presented with low confidence and are highly caveated.

6.2. Individual project cost data

6.2.1. Summary

The average heating system capex for each project (that was able to provide data) is shown in Figure 11. The two projects that achieve Aspects 1 and 2 of the Gold sustainability standard are shown separately at the top at the figure, given that these projects have lower average heating demands per unit than the others. Having a lower heat demand would imply lower LZCGT capex, but this cannot be verified in this case as these two Gold standard projects both incorporate the same technology and are the only projects to do so within this study.

The heating system capex of the projects meeting Silver standard are then presented, arranged by technology type. 'Extra capex' in the figure captures the costs of additional components that form the heating systems. For Project 15, this represents solar thermal water heating and MVHR (incorporated to meet other Aspects of Silver standard), and for Project 13 it represents heat batteries and PV on top of ASHPs.

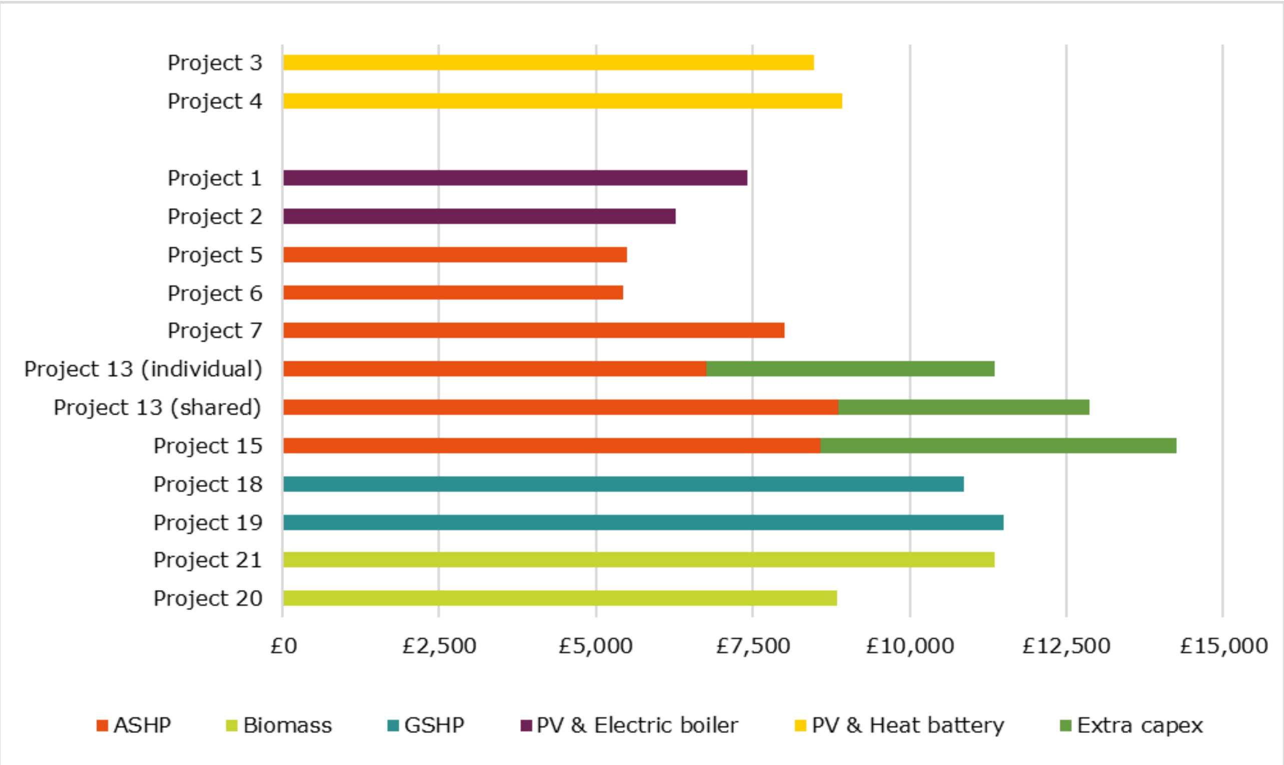

Figure 11: Average heating system capex for each project. 'Extra costs' are for those with additional technologies forming part of the heating system.

Figure 11 demonstrates several trends. Firstly, shared heating systems (Biomass, GSHPs and communal ASHPs) are more expensive than most individual systems. Secondly, for the projects that meet the same (Silver) sustainability standard, there is a vast range in heating system capex. Notably GSHPs and multi-component heating systems (both of which have significantly lower opex than ASHPs), cost more than double some of the ASHP systems. The variation between capex for a given technology is also evident from Figure 11, and most notably for ASHPs as there are more than two examples of this technology.

Lastly, it is evident that – despite the two Gold standard projects having lower annual heating demands than most project-averages and most individual units – a higher standard does not guarantee lower heating system capex. Of course, data from more projects achieving Gold standard would be needed to confirm or invalidate this across more technologies, but it holds true for the two examples above. Therefore, it highlights the premium that these two projects are paying for their heat batteries and solar PV, compared to the other individual technologies, on top of the premium they already encounter to meet Gold standard heat demands through building fabric specification.

6.2.2. Considerations

As Figure 11 separates projects only by technology type and sustainability standards, it fails to capture several other factors that have the potential to influence project capex. For example, in showing project-averaged values, it does not demonstrate variations in LZCGT capex across different unit types, sizes and occupancies, which was observed for some but not all projects. Most notably from the stakeholder interviews, rural and remote projects experience higher capex, mainly due to a less competitive supply chain. However, there is not sufficient data to verify this trend, given that this could only be attempted for ASHPs, but all ASHP projects in this study are in rural areas. The exception to this is Project 13, which is classified as an ‘Other Urban’ location due to its size, despite being highly isolated from the Central Belt and other large towns or cities. This project is also distinguished from the others which incorporate ASHPs in that it required high-temperature heat pumps to be specified as these are more compatible with heat batteries than standard ASHPs, but at a cost premium.

As with any element of built environment developments, the size of the project impacts its costs, with large projects experiencing economies of scale. A weak relationship between project size and capex for ASHPs is shown below in Figure 12. The key outlier against the trend of larger projects experiencing economies of scale is a development of four affordable homes which has the lowest ASHP capex. A potential explanation for this is the fact that it is a Section 75 requirement of a larger development.

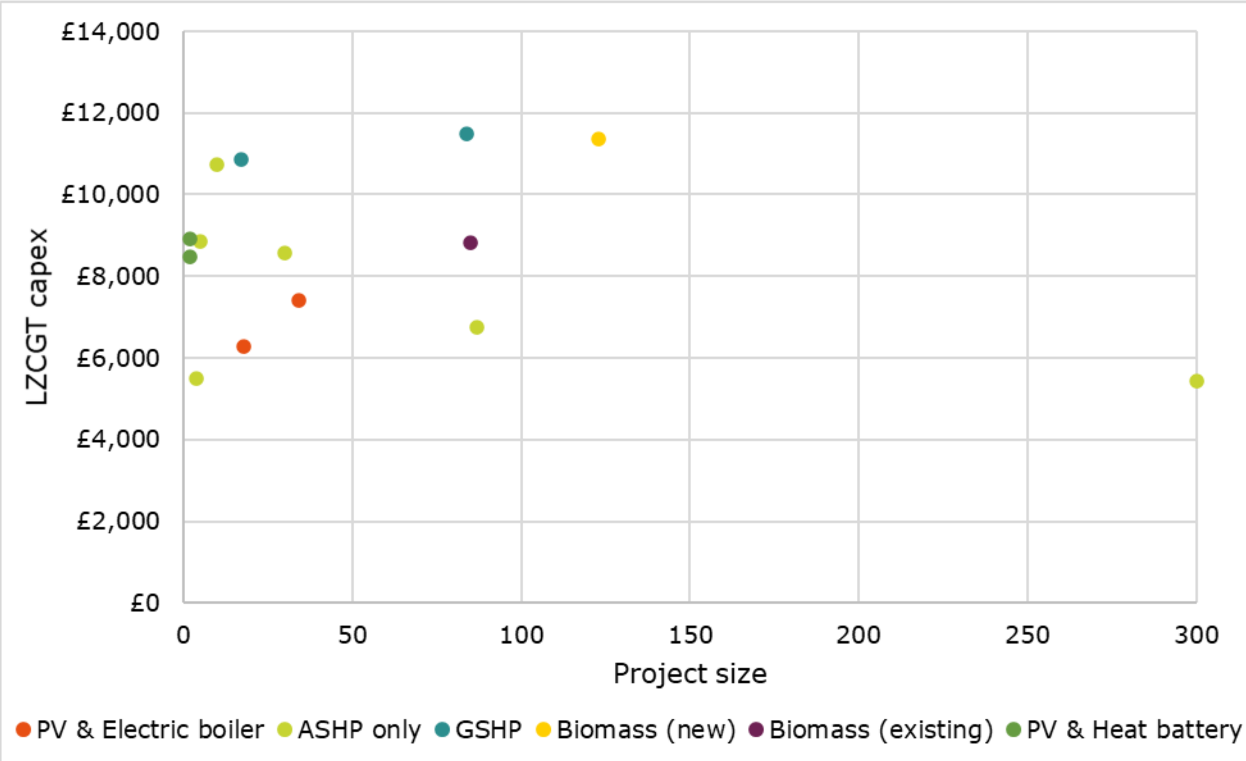

Figure 12: Project size vs LZCGT capex

Table 8 indicates that this project is one of two of the Section 75 projects across this study that incorporates the same heating system as the wider housing development. These two projects benefit from further economies of scale for their heating systems than the others, given that they tie into larger, private developments. This also raises another potential reason for varying costs – as these projects are linked to private developments which are understood to experience lower unit costs in general, as they often have better links with the supply chain and tend to have more buying power.

Project	Technology	Same technology/contract as rest of development?
Project 4	PV & heat battery	No
Project 5	ASHP	Yes
Project 7	ASHP	No
Project 19	GSHP	Yes
Project 20	Biomass DHN	No

Table 8: Impact of Section 75 on project capex

Whilst a few key trends have been demonstrated or inferred from the project capex data collected, all of the above considerations demonstrate that further data would be required to validate any and all of the quantitative trends identified within this study.

6.2.3. Solar PV heating systems (individual)

In Appendix B, section B1, costs are presented for the four projects that have rooftop solar PV arrays as the primary source of power for their heating systems. There are two variants, depending on whether the electricity produced by the solar PV is converted to heat via an electric boiler and hot water storage cylinder system or via a heat battery. The boiler/cylinder systems represent a more conventional hot water storage set-up that is long-established in domestic buildings. The heat batteries are a novel, proprietary technology from Sunamp which utilise a phase-change material to store heat and can be charged either by electricity or a thermal source. In this case, they would be charged from the PV arrays or by grid electricity, as would the electric boilers. Given that these two variants serve a similar purpose and are broadly cost-comparable, it has been deemed appropriate to group them for the purposes of this evaluation.

Project	Heating system	Sustainability Standard	Heat capex per unit	Number of units	Project total heat capex
Project 1	Solar PV & boiler	Aspect Silver Level 1 and 2	£7,408	34	£251,872
Project 2	Solar PV & boiler	Aspect Silver Level 1 and 2	£6,278	18	£112,004
Project 3	Solar PV & Heat battery	Gold	£8,470	2	£16,940
Project 4	Solar PV & Heat battery	Gold	£8,926	2	£17,852

Table 9: Solar PV heating system summaries

6.2.4. Air source heat pumps (individual)

In Appendix B, section B2, costs are presented for the five out of eight projects that have individual ASHPs as the primary component of their heating systems and were able to provide costs. The first three projects listed in Table 10 have ASHPs as the sole component of their heating systems. This applies to the Kilbeg project too, but the project costs were not received in this case. The final two have ASHPs along with one to three additional technologies, including MVHR, Solar PV, heat batteries and solar thermal hot water generation. Two further projects fit in this category, but one has not been designed to the point of costing yet and the project contact for the other was not able to get a breakdown of heating system costs from their contractor. Notably, of these four systems, no two use the same combination of additional technologies.

Project	Heating system	Sustainability Standard	Heat capex per unit	Number of units	Project total heat capex
Project 5	ASHP only	Aspect Silver Level 1 and 2	£5,500	4	£22,000
Project 6	ASHP only	Aspect Silver Level 1 and 2	£4,944 – £5,933	300	£1,654,211
Project 7	ASHP only	Aspect Silver Level 1 and 2	£10,738	10	£107,380

Project 13 (individual systems)	ASHP, Heat battery & PV	Aspect Silver Level 1 and2	£11,700–£13,119	87	£1,034,576
Project 15	ASHP, MVHR, Solar thermal	Silver	£14,137–£14,357	5	£71,125

Table 10: ASHP heating system summaries

6.2.5. Air source heat pumps (shared)

In Appendix B, section B3, information is presented for the only project that had costed shared ASHP heating systems. These systems are comprised of several large ASHPs located in a communal ‘energy centre’ room or building, which supply heat to multiple flats via insulated hot water pipes. As such, they represent a form of district heating. Two further projects employing shared ASHPs are at early pre-construction stages, so have no cost or energy demand data nor unit schedules yet.

Project	Heating system	Sustainability Standard	Heat capex per unit	Number of units	Project total heat capex
Project 13 (shared systems)	Communal ASHP, Heat battery and PV	Aspect Silver Level 1 and 2	£11,015	30	£330,436

Table 11: Shared ASHP heating system summaries

6.2.6. Ground source heat pumps (shared)

In Appendix B, section B4, costs are presented for the two projects which have shared GSHP heating systems. These are made up of a ground loop which extracts ambient heat from the earth via pipework installed in deep boreholes, and individual heat pumps in each property which use electricity to ‘upgrade’ the ambient heat collected from the ground to temperatures required for heating and hot water systems.

Project	Heating system	Sustainability Standard	Heat capex per unit	Number of units	Project total heat capex
Project 18	Communal GSHP	Aspect Silver Level 1 and 2	£10,871	17 (inc. 1x staff unit)	£184,800
Project 19	Communal GSHP	Aspect Silver Level 1 and 2	£11,500	84	£966,000

Table 12: Shared GSHP heating system summaries

6.2.7. Biomass (shared)

In Appendix B, section B5, costs are presented for the two projects which have shared biomass heating systems. These are comprised of a large, centralised biomass boiler which provides heat to each property via insulated hot water pipes in the ground. These two projects notably differ, in that one taps into an existing industrial scale DHN, whereas the other’s biomass plant is purpose-built.

Project	Heating system	Sustainability Standard	Heat capex per unit	Number of units	Project total heat capex
Project 20	Biomass DHN (existing)	Aspect Silver Level 1 and 2	£8,837	85	£751,106
Project 21	Biomass DHN (new)	Aspect Silver Level 1 and 2	£11,355	123	£1,396,665

Table 13: Shared biomass heating system summaries

6.3. Programme-averaged data

The heating system costs were collected across the affordable housing projects have been utilised to provide programme-averaged costs. For each technology and each unit archetype, programme-averaged capex has been calculated from the average equipment and installation cost based on the projects' costs for these systems and across different unit sizes. Similarly, programme-averaged opex values have been calculated for each technology and unit archetype, based on the estimated annual energy demands of each project's units and assumptions on the unit cost and performance of each technology type. Four archetypes have been defined on the basis of occupancy and range from one-bed to four-bed units, each with a defined floor area and annual heat demand. In Appendix A, the archetype definition process is explained, and an overview of the LZCGTs and counterfactual technologies considered is given.

6.3.1. Summary

The ranges of capex for each LZCGT and the three counterfactuals considered are presented below in Figure 13. The figure shows a very broad range in LZCGT capex, with shared systems being more expensive than individual ones in almost all cases. Table 14 demonstrates that LZCGTs are being installed at a premium of £2,000 to £5,000 compared with counterfactual systems. However, the counterfactual system capex values include solar PV installation capex as PV would be required for these systems to pass SAP. In addition, the off-gas counterfactuals are presented with a lower degree of confidence, given that most off-gas projects did not cost these systems. One explanation for this is that, owning to their high opex compared to LZCGTs, they are not considered viable systems due to high costs encountered by tenants.

Where gas is an option, it is actually more expensive to operate than the LZCGTs considered. GSHPs are cheapest to run, followed by ASHPs. Solar PV-based systems are slightly more expensive (although less so than direct electric or LPG systems) but there is more uncertainty around these costs as they are linked to the capacity and generation of solar PV. As with the individual projects' cost data, there are numerous limitations and caveats to the data programme-averaged presented within this section.

	LZCGT	Gas counterfactual	Off-gas counterfactuals
Capex range	£5,000 - £11,500	£3,000 - £6,500	£4,400 - £11,800
1-bed opex	£121 - £216	£216	£274 - £433
4-bed opex	£199 - £294	£294	£409 - £710

Table 14: Summary of LZCGT costs vs counterfactuals

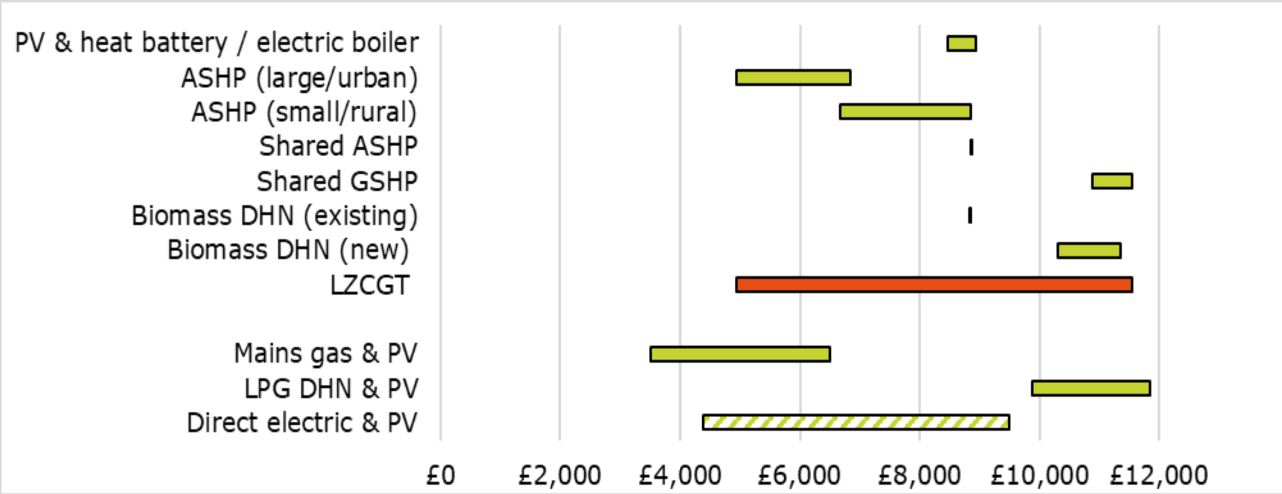

Figure 13: Programme-averaged capex ranges. (The range in LZCGT capex is shown in orange, based on the values above it; the range for direct electric and PV systems is shown partially shaded as its definition of capex contravenes that of the other technologies.)

6.3.2. Programme-averaged capex

Capex values for each LZCGT and the three counterfactuals, split by archetype, are presented in Table 15. Although several projects have defined capex in different ways, we have normalised costs where necessary to present values that can be compared across the range of technologies. Therefore, capex has been defined as the supply and installation of the heat generation and storage system, excluding heat distribution systems such as radiators and underfloor heating. Network costs are not included in the definition unless a network is inherent to the system design, as with GSHP, biomass, and LPG DHNs.

Given the varied availability of capex data, cells are colour coded in terms of the level of confidence that we have in the values presented. Red represents low confidence, meaning that the values are based on costs data for a single project and/or are specific to a narrow project context; green represents high confidence, meaning that cost data is based on multiple projects and/or are much less context-specific; and yellow represents medium confidence. All costs have been sense-checked, so even ‘low confidence’ values are considered reasonable if not universally applicable.

Archetype	1	2	3	4
Description	1-bed flat / terrace	2-bed flat/ terrace/ semi	3-bed terrace/ semi/ detached	4-bed semi/ detached
Footprint (m^2)	50	85	100	120
PV & Heat battery / Electric boiler capex	Not applicable	£8,470–£8,925	£9,000–£11,000	£9,000–£11,000
ASHP capex (large/ urban)[4]	£4,950–£6,680	£4,950–£6,680	£5,500–£6,840	£5,500–£6,840
ASHP capex (small/ rural)	£6,680–£8,460	£6,680–£8,460	£6,840–£8,680	£6,840–£8,680
Shared ASHP capex	£8,860	Not applicable		
Shared GSHP capex	£10,870–£11,500	£10,870–£11,500	£10,870–£11,500	£10,870–£11,500
Shared (existing) biomass capex	£8,835	£8,835	£8,835	£8,835
Shared (new plant) biomass capex	£10,300–£11,350	£10,300–£11,350	£10,300–£11,350	£10,300–£11,350
Mains gas boiler and PV capex	£3,000–£4,000	£3,500–£4,500	£4,500–£6,000	£5,000–£6,500
LPG DHN and PV capex	£11,015	£9,875	£10,375	£11,835
Direct electric heat and PV capex **(inc. heat distribution)**	£4,385	£5,500–£6,500	£7,000–£8,000	£8,500–£9,500

Table 15: Programme-averaged heating system capex.
(The colour coded cells represent the level of confidence in the values: red is low, yellow is medium and green is high.)

As in section 6.2, there is broad variation in capex costs across LZCGTs. Costs vary much less across the different archetypes, particularly for the shared systems. This indicates that the size and cost of equipment installed in a development does not scale linearly with unit sizes, which is broadly as expected, particularly in relation to shared systems. The costs presented for the counterfactual systems, whilst generally lower (with the exception of the LPG DHN option) are done so with lower confidence, predominantly because most projects did not cost a counterfactual system, and many of these were gas boiler cost estimates without corresponding solar PV requirements and costs.

[4] As in section 4 of this report, 'large' projects are those with more than 20 homes, and 'urban' and 'rural' definitions are as per the Scottish Government Urban Rural Classification. Costs for the single project, which is both large and rural, inform the large/urban classification as the project is the largest within the study and evidently encountered significant economies of scale for its heating systems.

For on-gas grid locations, RSLs and Councils appear to be paying a premium of £2,000 to £5,000 per unit to install an LZCGT with solar PV. In some cases, this equates to more than doubling the heating system cost. For off-gas grid locations, Table 15 shows significant variation in costs between the two options presented. However, the direct electric option includes distribution system costs inherently, which means that it cannot be directly compared to the other values presented. For all other systems, heat distribution costs are likely to range from £1,000 to £3,000 per property. As such (and as indicated during stakeholder interviews), we believe direct electric systems to be cheaper than LZCGTs in most cases. On the other hand, the costs presented for LPG DHNs indicate that this option is more expensive than the individual system options and comparable to the shared systems. Both counterfactuals were noted in the stakeholder interviews to lead to very high opex costs, which meant that they were not considered to be feasible alternatives for tenants in the way that gas boiler and PV systems were.

6.3.3. Programme-averaged opex

Programme-averaged opex values have been calculated for each technology and unit archetype, based on the estimated annual energy demands of each project's units and assumptions on the unit cost and performance of each technology type. This does not include maintenance costs.

In Table 16, the estimated annual heat demand for each archetype (inclusive of hot water demand) is taken from the average of the values of each unit with the same occupancy. Almost all the estimated heat demands are based on SAP calculations, which provides a degree of consistency between them, despite the fact that SAP is acknowledged among the stakeholders to generate estimates that do not translate into real-world demands. Therefore, it is stressed that the values in the table are not guaranteed to match real-world costs.

The operation costs within Table 16 are based on the Energy Saving Trust's (EST's) current rates for electricity (16.36p/kWh), gas (4.17p/kWh) and LPG (7.19p/kWh). Standing charges, also from EST, have been applied to gas (£93.93/year) and LPG (£62.41/year). Electricity does have a standing charge (£91.55/year) but this has been excluded below because it would apply to any home regardless of its heating system. The cost for biomass is taken to be equal to gas, as this is the benchmark that both of the biomass DHN projects had committed to deliver (although this was essentially a coincidence, as stakeholders from both projects stated they were not sure of a general approach to costing biomass DHNs fairly).

Lastly, the impact of solar PV has only been accounted for in the case where this has been defined as part of the heating system, for example where PV is linked to a heat battery or electric boiler. Although PV will be present in the gas, LPG and direct electric scenarios, it will not be linked to the heating systems and, as such, cannot be guaranteed to directly impact heating system costs. For Solar PV opex cost we have assumed that the PV system provides 40% of the energy demand, but the remaining 60% must be imported from the grid.

Archetype	1	2	3	4
Description	1-bed flat / terrace	2-bed flat/ terrace/ semi	3-bed terrace/ semi/ detached	4-bed semi/ detached
Footprint (m^2)	50	85	100	120
Annual heat demand (kWh/year)	2,645	3,150	3,155	4,340
Heat demand per m^2	52.9	37.1	31.6	36.2
Solar PV opex	Not applicable	£206	£206	£284
ASHP opex	£144	£172	£172	£237
GSHP opex	£124	£147	£147	£203
Biomass / gas opex	£216	£239	£240	£294
LPG DHN opex	£274	£314	£314	£409
Direct electric opex	£433	£515	£516	£710

Table 16: Programme-averaged heating system opex

It's clear that the heat demands for two-bed and three-bed units are very similar among the units represented within the project. This is partly due to the way that SAP estimates occupany for hot water demand calculations. This is calculated non-linearly and on a floor area basis, meaning that an 85m^2 home is assumed to have an occupancy of 2.44 people, versus 2.61 for a 100m^2 home. This means that the two-bed and three-bed archetypes units are assumed to have very similar hot water demands. Accordingly, the key differences in annual heat demand from the SAPs of these units would arise from heat loss through building fabric. Therefore, the footprints, locations and fabric specifcation of the units inform the heat demand, and the variation of the projects within the study appears to have resulted in similar programme-averaged demands. This highlights the need to collect real-world heat demand and system usage data over relying on averaged values based on SAP assumptions.

For ease of comparison, the values from Table 16 are also presented in Figure 14. Evidently, direct electric heating systems are by far the most expensive operationally, which explains why many of the stakeholders do not consider them to be a suitable option in the context of affordable housing where fuel poverty is a major concern. Similarly, LPG opex is higher than gas and LZCGT system opex. Stakeholders also indicated that they did not want their tenants to be tied into long-term LPG supply contracts, and suggested actual unit costs were considerably inflated compared to the EST values used in the study.

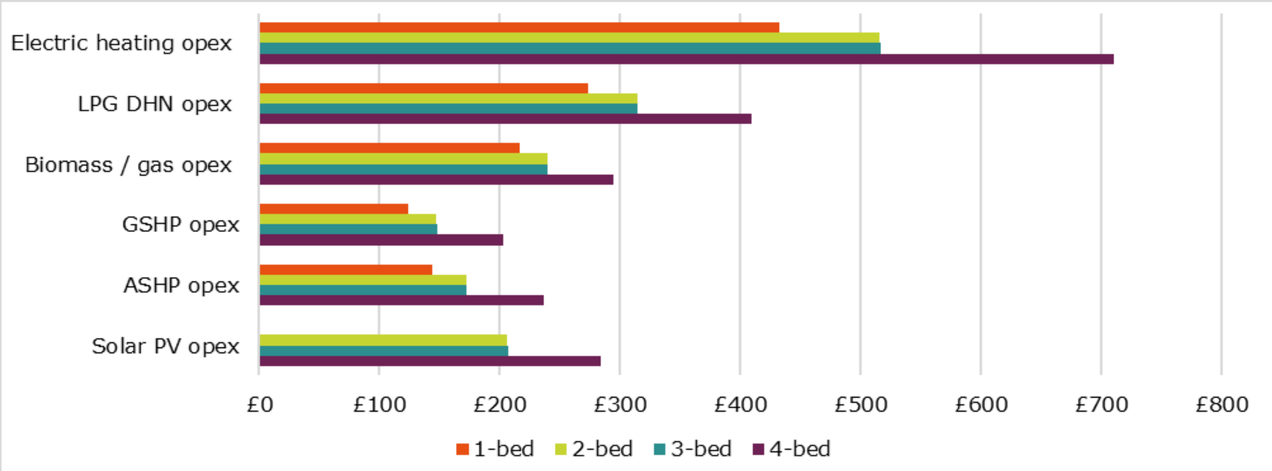

Figure 14: Programme-averaged heating system opex

Compared to the LZCGT systems, gas is more expensive heat source, and so therefore is biomass, so long as biomass costs are equal to those of gas. This is due to the standing charge applicable to gas, without which, it would be the cheapest option across all archetypes. Figure 14 also demonstrates that GSHPs are the cheapest LZCGT to operate, with GSHP running costs being lower by approximately 15% than those of ASHPs. Lastly, the solar PV-based systems are assumed to have the same running costs regardless of whether they include electric boilers or heat batteries. These sysems are estimated to be roughly 20% more expensive to operate than ASHPs, but this depends greatly on the contribution of solar PV generation to meeting heat demand.

Often, opex is defined to include maintenance costs as well as the fuel/electricity costs needed to run a heating system. This is not the case within this study, as costs to tenants are the main concern and maintence is arranged (and paid for) by the RSLs/Councils rather than the tennants themselves. Therefore, it is important to caveat that the opex costs presented above do not capture the full extent of the ongoing costs of operating each of these systems.

6.3.4. Discussion

Data availability and limitations

There are several discrepancies between the cost information requested by the Scottish Government and what has been presented above. This is primarily due to the approach of RSLs and Councils and the structure of their respective projects. For example, capex was requested to be separated into equipment and installation costs. However, no capex was provided in this way. This is because these costs are largely determined by contactors, who tend not to itemise equipment and installation separately.

Additionally, electricity network costs were requested for all projects but only one had determined that their heating system would trigger additional network costs, as an additional substation was required to handle the start-up power of the project's 97 ASHPs. Across the other projects, network costs were either not impacted by the choice of heating system, or the additional costs were not borne by the RSLs or Councils. Reasons for this are discussed in section 5.3.6. Therefore, network costs have not been estimated for the programme-averaged capex ranges.

In terms of counterfactuals, many have not costed any alternative systems, and those who did were more likely to compare costs of different LZCGTs to each other, rather than the cost of the chosen LZCGT heating system to an equivalent gas boiler system. One reason for this is that it is harder to define this ‘equivalent’ as e.g. gas systems would need additional measures, (namely solar PV) in order to meet the same sustainability standard (i.e. to achieve an equivalent rating in SAP).

SAP also appears to be relied on to provide annual energy demands and opex estimates, and only a handful of projects supplied data of this type that was not derived from SAP. Whilst SAP opex estimates are useful to allow the relative costs of different LZCGTs to be compared, they are widely acknowledged to be vastly different from (and unreliable measures of) real-life costs.

The analysis within this section is highly dependent on the assumptions made by the projects’ teams, by SAP and by Locogen. As such, real-life systems may vary widely from estimates, and it is important that in the coming years a shared knowledge base of actual operational costs for low and zero carbon heating systems is developed through data obtained from monitoring occupied homes.

Cost-effectiveness of LZCGT heating systems

It is inherently difficult to gauge which projects are more cost effective than others, given that they do not all aim for the same sustainability standards and they have a broad range of underpinning motivations. There is consensus across stakeholders that a cost-effective system is one that strikes an appropriate balance between capex and opex, and other non-cost aspects. However, given that the return on investment of these systems is not directed back to the RSLs or Councils but indirectly to their tenants, there is no clear metric for this balance, and it is essentially subjective.

ASHPs have been established in the stakeholder interviews as a ‘go to’ option because they are perceived to be the most cost effective LZCGT. The cost tables show that this perception holds true, as they are the second cheapest system to operate and the cheapest to install after gas. The fact that the capex figures vary so widely indicates that not all of the projects are experiencing this value to the same degree. In particular, the small or rural developments are paying more for ASHP installations, which appears to be due to the premium that they pay for suppliers to travel out to site. The larger developments are seeing lower capex due to economies of scale, and the urban developments have more competitive supply options. The exception to this trend is a rural project and only has four homes, but has the second lowest ASHP capex after the 300-unit project. This is likely because this project is developer-led as it constitutes the Section 75 requirement for a larger development.

Regarding the projects that include other technologies with ASHPs, they will benefit from significantly lower running costs (not captured in the programme-averaged values in Table 16) but these technologies do not necessarily allow for decreased ASHP capex. This was confirmed for one project, which added solar thermal water heating and MVHR in order to meet a higher sustainability standard (full Silver level), but did not switch to a smaller (i.e. cheaper) ASHP model after these additions. Similarly, one project incorporates heat batteries with PV and ASHP across all its homes, but its ASHP costs were significantly increased to accommodate the heat batteries, as these require heat pumps to operate at higher temperatures than is standard. Therefore, it was only possible for this project to include heat batteries because of the funding that it secured.

Arguably, the capex tables suggest that any projects using technologies other than or in addition to ASHPs will not achieve as good a balance between capex and opex. However, although significantly more expensive to install, GSHPs and biomass DHNs are shown to have lower operating costs, making them the most cost-effective options for tenants. The two biomass projects within this study were also strongly driven towards this option by planning policy and therefore had less choice in discerning value for money for these systems.

Lastly, trialling any LZCGT for the first time allows for Councils and RSLs to build their experience with new technologies, which offers value in other ways. This has been observed with two projects which used heat batteries for the first time – both in intentionally small projects (in both cases, two homes within a larger affordable development). These heating systems are not inherently cost effective, as they require sufficient solar electricity to be converted to heat to run at a cost that is competitive with the other LZCGTs considered.

7. Recommendations

Current new building regulations and sustainability standards can still be met by installing gas boilers. For a step change in LZCGT uptake in new builds by Councils, RSLs and the wider market, this would need to be addressed, especially in areas where a gas connection is more cost effective. The 2024 regulations for new builds will be a welcome change to help to push the use of LZCGTs and level the playing field between Councils and RSLs struggling to afford higher sustainability standards, and private developers with huge buying power. This could have knock-on effects to LZCGTs price reduction; customer awareness, acceptance and understanding of new heating systems; supply chain growth; and, more widely, boosting the green economy.

7.1. Summary of issues identified

The key findings from our project cost data analysis and stakeholder interviews are:

1. LZCGTs are £2,000 to £5,000 more expensive per unit than the default on-gas option of gas boilers with solar PV. For off-gas systems, there is no real default non-LZCGT option, so these projects are more likely to opt for LZCGTs than on-gas projects.
2. Default options are still being installed in new, on-gas affordable homes and can meet the highest sustainability standards (including Platinum and PassivHaus).
3. RSLs and Councils are leading the way in LZCGTs and sustainability standards compared with private developers, but there is a financial gap in meeting higher than Aspects 1 and 2 of Silver standard.
4. Rural and hard-to-reach areas are experiencing higher costs and a local skills gap, compared to urban and more accessible regions.
5. There is a gap in monitoring new LZCGTs, which could provide important evidence on real-world running costs.

7.2. Summary of recommendations

Based on our findings we recommend the following investigation, interventions and innovations to the Scottish Government to inform the development of the 2024 standards and ultimately increase the uptake of net zero affordable homes.

Investigation	1. Consider the costs of higher building fabric specification for all sustainability standards. 2. Further investigate the cost difference between sustainable homes standards, comparing like-for-like projects and costing new future requirements. 3. Analyse real-world running cost data for LZCGTs and compare to SAP estimates and the carbon-intensive counterfactuals. 4. Survey tenants to determine their comfort levels and overall satisfaction associated with their LZCGT systems.

Intervention	1. Continue affordable homes funding and greener standard premium and add a LZCGT premium to support additional cost. 2. Make cost breakdown reporting a standard requirement for affordable homes funding. 3. Facilitate best practice and knowledge sharing between LAs, RSLs and developers to support a higher penetration of LZCGTs. 4. Look into how to upgrade SAP to better specify LZCGT, predict running costs more accurately and include a wider variety of LZCGTs.
Innovation	1. Create a rural skills consortium to support rural developments. 2. Support innovative business models that might lead to subsidy-free, affordable, sustainable and net zero homes in the future. 3. Create price transparency on LZCGTs capex and opex to drive market growth. 4. Encourage energy suppliers to offer more attractive electricity tariffs for LZCGTs.

7.3. Matching our recommendations to your objectives

The table below demonstrates how our recommendations from this research match the New Build Heat Standard Objectives, as provided in the Scottish Government's scoping consultation in December 2020.

New Build Heat Standard: Key Outcomes	**Locogen's Recommendations**		
	Investigation	Intervention	Innovation
Outcome 1: Our new buildings no longer contribute to climate change	**1–3**	**1 & 3**	
Outcome 2: Reduced demand for heating and cooling	**1 & 3**	**4**	
Outcome 3: The cost of heating our new homes and non-residential buildings is affordable	**3**	**4**	**1 & 4**
Outcome 4: The systems we use in new buildings provide us with a reliable supply of heat		**1 & 3**	**4**
Outcome 5: Opportunities for retraining and upskilling of workforce across Scotland			**2–4**
Outcome 6: Informed, educated consumers	**4**		**1 & 3**
Outcome 7: Our indoor and outdoor spaces are filled with cleaner air		**1**	
Outcome 8: Our heating systems are smart, enabling the flexible and stable operation of our energy networks	**3**		**1 & 4**

Outcome 9: There is a continued supply of high-quality homes and non-residential buildings in line with identified requirements	4	3 & 4	4

Table 17: Alignment of recommendations with New Build Heat Standard Objectives

7.4. Detailed recommendations

7.4.1. Investigation

Building fabric capex

The stakeholder interviews have indicated that the main cost of meeting the Affordable Housing Supply Programme's greener standard is the enhanced building fabric that facilitates the heat demand per unit area that the standard requires. Collecting information on these costs was outside the scope of this report, but one stakeholder advised that the additional capex required to meet the greener standard for a rural project was in the region of £6–7,000. This is significantly greater than the £2,000 premium currently awarded for meeting the greener standard.

Additionally, stakeholders from a small, remote rural project in the north of Scotland advised that the project initially aimed to meet the greener standard but did not manage to do so within their project budget. As the greener standard relates to heat demand outputs from SAP (which assumes varying external temperatures across 21 regions in the UK, the lowest of which are in the Highland region), projects in the Highlands and Islands have a locational disadvantage, although the extent of this is not known to us. Given the additional supply chain costs for remote and rural regions widely noted from the stakeholder interviews, it is possible that projects in the Highlands and Islands (particularly small projects that benefit less from economies of scale) would have to specify higher performance building fabric and pay more to do so – essentially experiencing a double premium – in order to meet the greener standard.

Therefore, it is strongly recommended to investigate the costs that affordable housing projects incur in meeting the greener standard (based on Silver Aspect 2), and also Gold Aspect 2, compared with meeting the minimum requirements of current building regulations. Various project sizes, housing mixes and locations (including urban, costal, rural and remote) should be represented in order to determine whether or not there is a level playing field across Scotland in terms of these costs. Whilst information from real projects is always valuable, based on the stakeholder interviews and heating system cost data received, we would not expect all projects to have this information (mostly due to how architects and contractors are briefed and how they share information with RSLs and Councils). Therefore, we would recommend that the Scottish Government commission a desktop study, as this would allow for SAP outputs and building fabric requirements and costs to be compared with identical units across various project scales and locations.

Further investigate LZCGT capex variations

The cost data received for this study, as well as anecdotal evidence from the stakeholder interviews, suggest that there is a difference in LZCGT installation capex (and other housing development costs) between rural and urban locations. This was particularly true for ASHPs, although only because most participating projects used these and most stakeholders had more experience with ASHPs than other technologies. Economies of scale in larger projects were also observed. However, given the range of LZCGTs, project sizes, locations and sustainability standards, there is not sufficient data across the projects to confirm these trends.

In order to validate these suspected trends, it would be necessary to compare capex from projects of the same size, sustainability standard and housing mix in various locations, and ensure a like-for-like comparison between LZCGT specification (for example, the costs of high performance and/or high-temperature heat pumps should not be compared against basic models). This investigation would provide further evidence as to whether the higher grant subsidy benchmark for rural and remote projects under the Affordable Housing Supply Programme is proportionate.

This evaluation could be supported by the disclosure of the costs and exact specification of heating systems as a condition for future Affordable Housing Supply Programme grant awards (as per our second Intervention recommendation). Additionally, or alternatively, a desktop investigation could be carried out through a hypothetical procurement exercise undertaken by an appointed consultant or quantity surveyor, in which installation quotations could be sought for small and large developments in urban, rural, remote and costal locations in order to allow like-for-like comparisons. Of course, this approach would not accurately represent the realities of installation costs and locational variations.

Monitoring real-world LZCGT running-cost data

As discussed in Section 5.6, energy data monitoring is not commonplace, unless third-party metering is needed because there is a communal heating system, or if it is required as a condition of additional innovation funding or a wider research programme. However, all stakeholders plan to carry out some form of post-occupancy survey. There is an appetite for further monitoring beyond surveys among all of the stakeholders we spoke to, as they are keen to understand the true running costs of LZCGTs for internal purposes. This itself highlights the need for more real-world data to become publicly available.

Among the projects that involve some degree of data monitoring, there was general interest in being contacted by and collaborating on monitoring with the Scottish Government. The main issue raised was that any additional monitoring carries a cost and resourcing requirement, as it is unlikely to be factored into each projects' plans. Regardless of whether a project has an existing or intended data monitoring programme, there are opportunities for the Scottish Government to intervene, as summarised in Table 18. Table 19 shows the breakdown of monitoring plans and intervention priority by project.

Locogen would recommend that a minimum of one full year's data be collected, but ideally three years' worth. That said, if time and cost resources are limited, it would be most useful to capture data from winter, as heating demands would be highest over this period. The first insight that should be captured from data monitoring is a comparison of external temperatures against actual and modelled heat demands (from SAP outputs and/or a consultant's domestic energy model). This would demonstrate the impacts of user interaction and in-situ performance against expectations. Secondly, the LZCGT opex should be compared to SAP and other opex estimates made, in order to highlight the true costs to tenants to operate the systems. This is a particularly important insight for affordable housing, as fuel poverty was raised as a key concern amongst the stakeholders interviewed.

For PV- and heat pump-based systems, data monitoring (heat metering in particular) would be strongly recommended over analysing heating system costs from electricity bills, in order to avoid having to estimate the contribution of other domestic loads to total electricity demands. The results from this exercise should be shared in the public domain, as they will be of great benefit to all RSLs and Councils as they will clarify which technologies are most cost-effective for their tenants. The results will also benefit private developers, tenants and homeowners and the SAP and wider heating policy community.

Finally, for any energy data monitoring process, it is strongly recommended that this is carried out alongside an understanding of the occupancy and usage of the buildings, as this will allow much more accurate clustering and analysis of the data to explain how the homes are used in reality.

Intervention priority	Construction phase	Monitoring	Intervention strategy and rationale
1	Pre-construction	Extensive Monitoring	Connect with projects pre-construction that are planning extensive monitoring to find out more about their plans, feed into existing plans and ask for the results. There is potential to provide further support to meet the Scottish Government's own objectives with already energised RSLs/ Councils and pre-occupancy projects.
2	Complete	Monitoring or tenant agreement to monitor	Intervention with these RSLs/ Councils is time critical given sites are complete. Two projects have tenants' agreement to monitor but are at an early stage of what this should include and how they should do this. This provides an opportunity for the Scottish Government. This project had intentions for extensive monitoring with a university, but lost this funding. They are intending to monitor properties to identify the differences between homes with bronze–platinum standards. Given the variety of standards met at this site, this presents an interesting learning opportunity for the Scottish Government to intervene.
3	On-site / pre-construction	No monitoring plans but open to consider	There is an appetite to undertake monitoring to find out the 'real' running costs of LZCGTs. However, these RSLs currently have no plans and have not costed for monitoring equipment in their projects. Given the early stage of these projects, we see this as an opportuntiy for the Socttish Government to provide additional funding and guidance on monitoring to these RSLs/Councils. We suggest that the Government would likely need to define the objectives of monitoring, specify equipment, provide data analysis support and other relevant tasks.
4	Delayed	Unknown	Engaging now with these projects prior to commencement could provide a way to ensure monitoring occurs. However, no interviews were undertaken with these stakeholders, therefore willingness to engage, plans to monitor etc were not qualified.
5	Complete	No monitoring plans	There is only one project that is complete with no monitoring equipment. There could be an option to add questions into post-occupancy surveys. Installing monitoring equipment post-occupancy will likely be more difficult and costly to undertake. The RSL had not thought

			about monitoring for this project, but were prompted by our questions. They are likely to be open to a discussion with the Scottish Government for this or future projects.

Table 18: Monitoring intervention priorities

#	Heating system	Progress	Monitoring planned		Priority
1	Solar PV & Electric boilers	On site	✗	Tenant surveys	3
2	Solar PV & Electric boilers	On site	✗	Tenant surveys	3
3	Solar PV & Heat battery	Complete	✓	Have agreement from two tenants to return to monitor	2
4	Solar PV & Heat battery	Complete	✓	Data loggers ordered. Two tenants agreed to monitoring	2
5	ASHP	Pre-construction	✗	Tenant surveys	3
6	ASHP	On site	✗	Tenant surveys and usage data for first 38 homes, via bills	3
7	ASHP	Complete	✗	Tenant surveys	5
8	ASHP	Pre-construction	✓	Extensive monitoring, part of research project	1
9	ASHP	Pre-construction	✗	Tenant surveys. Want to do more but cost issues	3
10	ASHP	Delayed	✗	N/A	4
11	ASHP	Delayed	✗	N/A	4
12	ASHP & MVHR	Delayed	✗	N/A	4
13	ASHP, Solar PV & Heat battery	Pre-construction	✓	IoT sensors in a small number of homes. Usage data from third- party metering and billing for flats with shared ASHPs	1
14	ASHP, MVHR & Heat battery	Complete	✓	Extensive monitoring of ten homes built to different sustainability standards.	2
15	ASHP, MVHR & solar thermal	On site	✗	No plans, but open to explore monitoring	3
16	Shared ASHP	Pre-construction	✓	Heat metering and extensive monitoring, part of research project	1
17	Shared ASHP	Pre-construction	✓	Extensive monitoring and surveys, part of research project	1
18	Shared GSHP	Pre-construction	✓	Usage data from third-party metering and billing	1

19	Shared GSHP	On site	✓	Usage data from third-party metering and billing	1
20	Shared Biomass	On site	✓	Usage data from third-party metering and billing	1
21	Shared Biomass	On site	✓	Usage data from third-party metering and billing	1

Table 19: Project monitoring plans and intervention priorities

Surveying tenants' satisfaction with LZCGT heating systems

All stakeholders indicated that they planned some form of interaction with their prospective tenants with regard to heating systems, including guidance on usage and energy tariffs, as well as surveys on their general impressions of the systems. Several stakeholders who were trailing new technologies were particularly relying on tenant feedback to determine whether they would include these in future projects. Clearly, there is much insight to be gained from surveying tenants. So we recommend that a standardised survey is issued to numerous, if not all, tenants across the projects participating in this study. This survey could later be issued as a template to all RSLs and Councils receiving Affordable Housing Supply Programme funding, so that further standardised information can be collected in the future. The survey should be designed to collect feedback from tenants across various themes, including general thermal comfort, ease of operation and perceptions of heating costs compared with traditional systems (most likely gas boilers). The responses could then be analysed by a consultant to determine the key areas of satisfaction and concern for tenants. The consultant could then provide suggestions to mitigate any common issues, provide additional support to tenants and potentially, depending on the strength of the findings, guide RSLs towards (or away from) certain technologies in future projects.

7.4.2. Intervention

Continue affordable homes funding, providing a premium for LZCGTs

A key finding from our stakeholder interviews was that the current affordable homes funding was deemed necessary for RSLs to use LZCGTs in new homes. All stakeholders try to meet Silver standards and would like to meet higher standards, but often the cost is prohibitive. RSLs and Councils use the affordable home grants to cover the gap between their own funds and private finance, hence the funding does not fully cover the costs on its own. The grants are not a direct incentive for LZCGTs, as the greener sustainability standard can be met without LZCGTs as it is achieved primarily through the building fabric specification. It is also important to note that there are many aspects of the higher sustainability standards that add cost, but do not relate to energy, such as requirements for home offices and bike storage space. We found that often there is limited incentive to aim higher than Silver Aspect as the cost of the other sustainability measures increases project costs.

The Scottish Government should decide what they want RSLs to prioritise in affordable homes to make the funding as cost effective as possible to achieve these key goals. If the Scottish Government wants to increase LZCGT adoption in affordable homes, they might want to change the structure of the funding, or add a premium specifically for LZCGTs. For example:

- Allow higher grant awards for DHNs (including GSHPs, shared ASHPs, biomass) as these are more expensive. Particularly GSHPs and biomass, which have lower running costs to tenants.

- To accelerate the uptake of LZCGTs prior to introduction of the 2024 regulations, the Scottish Government should amend the greener standard so that projects with gas or other fossil fuel boilers cannot qualify (i.e. meeting Bronze Active and Silver Aspect 2 standards).

Changing and new regulations can increase costs of new builds too, such as improved fire sprinkler systems, and this will have an impact on future projects, which needs to be considered alongside this recommendation.

Enforcing LZCGTs cost breakdowns as a requirement of funding

To improve the Scottish Government's own cost efficiencies when continuing to investigate LZCGTs, we recommend updating the guidelines and requirements of the funding applications. This would effectively remove the need for future studies on the same topic and instead allow the Scottish Government to collect the data and insight you need to make decisions on LZCGTs directly. This could provide benefits to not only new build regulations and affordable homes grants, but also other net zero related policy decisions. It also ties into some of our other recommendations, e.g. on facilitating best practice and creating price transparency to help boost the market.

A key finding from the interviews was that cost data was collected in many ways, across different stakeholders, with a variety of assumptions etc, indicating that there is no normalised way of collecting, consolidating, or communicating this type of information back to the Scottish Government. We recommend that the Scottish Government standardises this with the following considerations:

- Provide a concise, standard and easy to understand cost template for RSLs/Councils to complete as a requirement for funding. This increases the data the Scottish Government has access to without the need for additional consultancy projects to collect data retrospectively. It also allows more accurate and direct cost comparison across projects.
- It is important to consider the administration time and cost of additional administration tasks and keep any additional prerequisites to a minimum, e.g. consider replacing requirements rather than creating additional ones.
- We recommend working with RSLs/Councils to design the template to ensure it also provides benefits to them, whether that is easy and less timely to fill in, helps them justify to contractors what data they require, or helps provide greater transparency in procurement.

Engage more with RSLs and facilitate best practice

Most of the RSLs and Councils we spoke to were happy to be contacted by the Scottish Government and were eager to provide feedback to us for them, to help highlight the issues associated with LZCGTs. Given their vast, first-hand experience beyond the projects we interviewed them about, we would recommend communicating directly with RSLs and asking for continuous feedback to support future policy decisions.

There is a potential role the Scottish Government could play in facilitating best practice, which could include:

- Facilitate knowledge sharing between RSLs and Councils to help save time, use more cost-effective approaches, and increase the use of LZCGTs in new builds. For example, two stakeholders discussed their first biomass DHN project and independently reached the same conclusion on benchmarking gas fuel costs to biomass fuel costs. This could have been shortcut if they had spoken to each other, and it could accelerate other stakeholders to engage in more uncertain technology options. A second example is sharing learnings from an RSL that is exploring becoming an energy services company (see Figure 15).

- Publish best practice and knowledge-sharing findings to support RSLs and increase the use of LZCGTs as a default.
- Facilitate knowledge sharing and best practice between RSLs and private developers to help developers get onboard with LZCGTs. Private developers were noted by several stakeholders to be behind in terms of LZCGT uptake and meeting higher sustainability standards.

SAP requires a long overdue upgrade

From our stakeholder conversations, and from our own knowledge, SAP has been a long-term issue for the housing industry and specifically LZCGTs. SAP is owned by BRE (Building Research Establishment), so the Scottish Government has limited control over direct intervention. However, this research (and perhaps other Scottish Government or publicly available research) could be shared with BRE as an evidence basis for improving the software.

Given BRE is a charity, they may be limited by funding. It might be worth considering if the UK Governments can collaborate and combine funding to support BRE to upgrade SAP, which is a fundamental tool for the housing industry and could be used more effectively to drive net zero ambitions.

Improvements to SAP, with reference to this study, could include, for example:

- A review of operational cost assumptions to bring these in line with real-world costs.
- Updated emissions ratings to avoid penalisation of electric vs gas, especially on-gas.
- Ensuring that new LZCGT types and models can easily be incorporated.

7.4.3. Innovation

Create a rural skills consortium

It is well established and confirmed through our stakeholder interviews that there is a rural skills gap in the Highlands and Islands for LZCGTs, which impacts the cost of new affordable homes. The Scottish Government could spearhead a rural skills consortium which could:

- Make visible the skills gap by creating a map and listing for all relevant companies and services offered, including new build developers, LZCGTs installers as well as maintenance professionals.
- Celebrate and support local businesses offering building services and LZCGTs.
- Make the skills gap more visible to help attract new businesses to specific areas, which could provide more competition and hence price-competitive services to these areas.
- Identify areas that are particularly difficult to reach but require new homes, and incentivise new businesses to establish there.
- Upskill local residents who are interested in becoming e.g. installers and provide funding to help them secure the necessary training.

Business model innovation support

Examine, promote and support innovative business models that might lead to more cost-effective (or even subsidy-free) affordable homes in the future. It is important to stipulate that all stakeholders interviewed were clear that the current Government funding does not cover the additional cost of current sustainability levels for affordable homes. There are also market and regulatory barriers to some innovative business models, e.g. to peer-to-peer trading of excess generation. However, there are numerous innovations in approaches and business models that could apply to RSLs/Councils and new affordable homes that could drive cost efficiencies and increased penetration of LZCGTs, such as:

- Local energy system models that can optimise renewable generation, heating and storage assets on a site-wide basis. This could lead to lower network connection charges for new build sites that are managed locally to mitigate constraints.
- RSLs adapting their business model to the energy services model. This would incentivise RSLs to operate LZCGTs in the most cost-effective manner to create a return on their investment. This would include monitoring, metering, billing and maintaining LZCGTs. This would in turn ensure tenant comfort and affordability. (See Figure 15 below.)
- Encouraging energy suppliers to offer ‘heat-as-a-service’ models that could help tenants optimise their heating for comfort and make it more cost effective.

Business Model: Energy Services Model

Stakeholder: RSL

This RSL was particularly active in LZCGTs and had a proactive company-wide strategy to specify ASHPs over gas boilers ahead of the 2024 regulation change.

Given their experience with LZCGTs, they had started to face new projects well suited to communal heat pumps and district heating networks, seeing this as a good solution for e.g. flats. The key issue with these types of development is trying to meter and bill tenants individually. After completing a few projects with third party metering and billing companies, they decided to develop these capabilities inhouse, foreseeing that they would be involved in many similar projects in the future.

They are currently working towards becoming a type of energy services company as well as an RSL, so that they can properly manage their new build sites with communal LZCGTs and also district heating.

Figure 15 : Innovative Business Model example from stakeholder interviews

Create price transparency for LZCGTs

We identified a potential issue in the price points set by installers from both RSL and industry-supplier interviews. Publishing data on low carbon technology costs to manage expectations and provide more bargaining power to RSLs and end users could facilitate a faster adoption of LZCGTs as well as build customer confidence and trust. A secondary benefit is that the Scottish Government would also see price development and be able to update the right funding available without the need for external support.

Linking to our recommendation on facilitating best practice and standardising costs from affordable homes projects, the Scottish Government would have enough data and insight to publish this themselves. They could also engage with the Energy Saving Trust, Which, the Money Saving Expert or other consumer-facing channels to facilitate or publish this.

Encourage market development of smarter electricity tariffs for electric heating technologies

During our stakeholder interviews, we found that there were experienced and perceived issues with electricity tariffs for heat pumps. This included the concern over high electricity prices (compared to gas), tenants operating heat pumps incorrectly, and the lack of tariffs designed for heat pumps. As well as functioning in a different way to gas boilers, the cost of electricity is higher than gas and so using the heat pump in the correct way is important to ensure that affordable homes are in fact affordable to heat. Knowing which tariffs are available and having the right heat pump controls therefore becomes vital.

There are very few examples of dynamic Time-of-Use (ToU) tariffs in the UK, and even fewer specific heat pump tariffs. A couple of examples include Good Energy heat pump tariff and Octopus Energy ToU tariff. The majority of mainstream energy suppliers do not yet offer these types of tariffs, and the few tariffs that are available are not well known to RSLs or tenants. In addition to availability of tariffs, having the right heat pump controllers that can automatically respond to energy price signals is also required.

The Scottish Government could support the market development of new and smarter electricity tariffs by encouraging Scottish energy suppliers to offer dynamic ToU tariffs or heat pump-specific tariffs, and inputting into OFGEM discussions on energy retail tariffs and energy market reforms. Any tariff created for tenants (or the wider market) needs to be automated, attractive, easier to understand and suitable for the given technology.

Appendix A. Programme-averaged data definitions

Archetypes

Four typical housing unit archetypes have been identified, based on the unit schedules received and heating to date. Whilst there are numerous layout variations in the units across projects, the floor area and estimated heat demands do not vary in any discernible patterns for a unit with a given number of bedrooms. For example, the range of two-bed units includes flats, bungalows, terraces and semi-detached homes, but floor areas are largely similar across these variations. As such, the archetypes have been defined based on occupancy and the most common layout variations have been used in the description for each one.

Technologies

Solar PV heating systems (individual)

There are no examples of solar PV and heat battery/electric boiler systems in one-bed flats amongst the projects considered. Therefore, no costs are presented for this first type. The reason for this is very likely that these systems need extensive solar PV capacity in order to be cost effective to tenants, and this cannot be accommodated on shared roofs in flatted buildings. Two similar capex values were presented for projects aligning with the second archetype, so these are high-confidence values and have been used to inform medium confidence values for larger archetypes.

Air source heat pumps (individual)

Five projects have provided capex for heating systems with individual ASHPs. Only the costs for the ASHP units have been accounted for in Table 15 (so additional technology costs, where applicable, have not been included). However, due to the wide variation in costs amongst these six projects, capex has been split into high and low estimates for small and/or rural developments, and large and/or urban developments. The wide range of data provided allows for medium-to-high confidence in the values presented.

Air source heat pumps (shared)

As shared ASHP systems have been found to be preferred only for flats, capex has only been presented for the one-bed archetype. Only one project has supplied a cost per unit, so the capex has been presented with low confidence.

Ground source heat pumps (shared)

Two projects in the evaluation have costed GSHPs. While the costs obtained are very similar, they are presented with medium confidence as site-specific factors can cause variations in GSHP that are not captured in these projects.

Biomass heat (shared)

Costs have only been collected for two types of biomass DHN – one which is an extension of an existing heat network, and a purpose-built one. As such, these two systems have been differentiated in Table 15. Additionally, one project costed a biomass DHN as a counterfactual, so this is included in the range for purpose-built DHNs. As with GSHP costs, these values are of low-to-medium confidence due to site-specific factors that may not be captured.

Counterfactuals

Gas boilers are the primary counterfactual heating system for the evaluation, although this can only be applied to projects located on the gas grid. For off-gas locations, LPG DHNs have been chosen as the key counterfactual as they were mentioned by several participating projects. Costs for direct electric systems have also been presented, although with the caveat that these *cannot be directly compared with the costs of the other technologies*, given that they incorporate electric radiators and therefore inherently include heat distribution costs, which fall outside of the capex definition for the other technologies.

Several stakeholders have advised, in agreement with our understanding of Scottish building standards, that fossil fuel and direct electric systems require additional energy efficiency measures to pass SAP. The most common approach to achieving this is to add sufficient solar PV capacity. Therefore, the counterfactual capex values in Table 15 include solar PV.

For the mains gas boiler option, values are presented with medium-to-high confidence because several capex values for boilers were collected, although only a handful shared the corresponding solar PV costs. LPG DHN costs are presented with low confidence as only one project provided capex values, and, as with other DHNs, these will be site-specific. Direct electric system costs are presented with low confidence as only one project provided capex values, which applied to one-bed terraces only.

Appendix B. Individual project data

B0. Overview

In this appendix, the information collected for each project is presented in two tables – an overview and then a per-unit cost breakdown. The second table has not been included if insufficient data was provided, and this is explained in the project's overview. If data is not available but it has been possible to estimate a value, cells are shaded in **blue** and the estimation is explained underneath. Where information is yet to be established because the project is at an early stage, cells are shaded in **purple**.

An example overview table is provided below, which lists and explains the metrics considered for each of the projects.

Metric	Information
Location	The project's local authority area
Unit count	The number of affordable housing units included in the project
Unit types	The number of different affordable housing unit types included in the project
Progress	Whether the project is in the pre-construction phase, under construction or complete
On-gas grid	Whether the project is situated on or off the gas grid
Section 75	Whether or not the project forms the Section 75 affordable housing obligation for a larger development
Sustainability target	The energy demand target that the project is designed to achieve
Heating system	The technology (or technologies) that are included in the project's heating and hot water generation and storage system
Capex extent	The components and services included in the capital expenditure (capex) cost provided
Capex source	The source of the capex figure
Opex	Whether the project estimated an operational cost (opex) to the occupants to run the heating system
Counterfactual	Whether the project has costed an alternative (counterfactual) heating system

Table 20: Example project overview

B1. Solar PV (individual)

Project 1

An overview of Project 1 is provided in Table 21. A per-unit table has also been provided.

Metric	Information
Location	North Ayrshire
Unit count	34
Unit types	7
Progress	Under construction
On-gas grid	No
Section 75	No
Sustainability target	Aspect Silver Level 1 and 2
Heating system	Rooftop solar PV modules, electric boiler
Capex extent	Installed costs of PV, boiler
Capex source	Averaged actual costs
Opex	Estimates provided
Counterfactual	None considered

Table 21: Project 1 overview

Unit	1	2	3	4	5	6	7
Description	2-bed mid (A)	2-bed mid (B)	2-bed end	2-bed bungalow	2-bed WC bungalow	3-bed det.	4-bed WC det.
Count	3	6	8	8	2	3	4
Footprint (m^2)	88	84	83	63	63	119	112
Heat demand	3598	3523	3902	3485	3561	5227	5000
Heat demand per m^2	41.0	41.7	47.1	55.4	56.6	44.0	44.6
Installation capex	£5,538	£5,538	£5,538	£5,538	£5,538	£5,538	£5,538
PV capex	£1,870	£1,870	£1,870	£1,870	£1,870	£1,870	£1,870
Network capex	Not considered						
Total capex	**£7,408**	**£7,408**	**£7,408**	**£7,408**	**£7,408**	**£7,408**	**£7,408**
Capex per m^2	£84.4	£87.8	£89.5	£117.8	£117.8	£62.4	£66.0
Est. opex	£475	£465	£515	£460	£470	£690	£660
Est. opex per m^2	£5.4	£5.5	£6.2	£7.3	£7.5	£5.8	£5.9

Table 22: Project 1 costs per unit

Project 2

An overview of Project 2 is provided in Table 23. A per-unit table has also been provided.

Metric	Information
Location	North Ayrshire
Unit count	18
Unit types	7
Progress	Under construction
On-gas grid	No
Section 75	No
Sustainability target	Aspect Silver Level 1 and 2
Heating system	Rooftop solar PV modules, electric boiler
Capex extent	Averaged actual costs
Capex source	Actual costs
Opex	Estimates provided
Counterfactual	None considered

Table 23: Project 2 overview

Unit	1	2	3	4	5	6	7
Description	3-bed end	3-bed terrace	2-bed end	2-bed mid	2-bed WC bungalow	3-bed WC det.	4-bed WC det.
Count	1	2	7	2	3	2	1
Footprint (m^2)	96	93	63	63	63	119	143
Heat demand	4205	3712	3598	3333	3598	5152	6606
Heat demand per m^2	44.0	39.9	57.2	53.3	57.2	43.4	46.3
Installation capex	£4,675	£4,675	£4,675	£4,675	£4,675	£4,675	£4,675
PV capex	£1,603	£1,603	£1,603	£1,603	£1,603	£1,603	£1,603
Network capex	Not considered						
Total capex	**£6,278**	**£6,278**	**£6,278**	**£6,278**	**£6,278**	**£6,278**	**£6,278**
Capex per m^2	£65.7	£67.5	£99.8	£100.4	£99.8	£52.9	£44.0
Est. opex	£555	£490	£475	£440	£475	£680	£872
Est. opex per m^2	£5.8	£5.3	£7.6	£7.0	£7.6	£5.7	£6.1

Table 24: Project 2 costs per unit

Project 3

An overview of Project 3 is provided in Table 25. A per-unit table has also been provided.

Metric	Information
Location	North Ayrshire
Unit count	2
Unit types	1
Progress	Complete
On-gas grid	No
Section 75	No
Sustainability target	Gold
Heating system	Rooftop solar PV modules, Sunamp heat battery
Capex extent	Sunamp and PV installation
Capex source	Actual costs
Opex	Estimates provided
Counterfactual	Gas boilers and PV to meet Silver Aspects 1 and 2

Table 25: Project 3 overview

Unit	1
Description	2-bed terrace
Count	2
Footprint (m^2)	85
Heat demand	3462
Heat demand per m^2	40.5
Installation capex	£4,950
PV capex	£1,603
Network capex	Not considered
Total capex	£3,520
Capex per m^2	**£8,470**
Est. opex	£99.2
Est. opex per m^2	£269
Alt capex	3.1
Alt capex per m^2	**£4,180**
Est. alt opex	48.9
Est. alt per m^2	309

Table 26: Project 3 costs per unit

Project 4

An overview of Project 4 is provided in Table 27, and per-unit data in Table 28. A partial data set has been provided for this project, so the units' heat demand has been estimated.

Metric	Information
Location	North Lanarkshire
Unit count	2
Unit types	1
Progress	Complete
On-gas grid	Yes
Section 75	Yes
Sustainability target	Gold
Heating system	Rooftop solar PV modules, Sunamp heat battery
Capex extent	Heating system installation, including electrician costs
Capex source	Developer
Opex	Not provided – estimated from maximum Gold heat demand
Counterfactual	Not costed

Table 27: Project 4 overview

Unit	1
Description	2-bed semi
Count	2
Footprint (m^2)	83
Heat demand	2502
Heat demand per m^2	30
Installation capex	£4,132
PV capex	£4,794
Network capex	Not considered
Total capex	**£8,926**
Capex per m^2	£107.0
Est. opex	£246
Est. opex per m^2	£2.9

Table 28: Project 4 costs per unit

B2. Air Source Heat Pumps (Individual)

Project 5

An overview Project 5 is provided in Table 29, and per-unit data in Table 30. All available information is included, although a counterfactual has not been costed.

Metric	Information
Location	Perth & Kinross
Unit count	4
Unit types	3
Progress	Pre-construction
On-gas grid	No
Section 75	Yes
Sustainability target	Silver
Heating system	ASHPs only
Capex extent	Heating system installation
Capex source	Developer's estimates
Opex	Developer's estimates
Counterfactual	Direct electric heaters (costs not provided)

Table 29: Project 5 overview

Unit	1	2	3
Description	3-bed semi	2-bed GF flat	2-bed 1F flat
Count	2	1	1
Footprint (m^2)	99	60	70
Heat demand	5639	3656	4321
Heat demand per m^2	57.0	60.9	61.7
Installation capex	£5,500	£5,500	£5,500
Network capex	Not considered		
Other heating capex	N/A		
Total capex	**£5,500**	**£5,500**	**£5,500**
Capex per m^2	£55.6	£91.7	£78.6
Est. opex	£437	£366	£400
Est. opex per m^2	£4.4	£6.1	£5.7

Table 30: Project 5 costs per unit

Project 6

An overview of Project 6 is provided in Table 31, and per-unit data in Table 32. All available data has been shared.

Metric	Information
Location	Argyll & Bute
Unit count	300
Unit types	8
Progress	Under construction
On-gas grid	No
Section 75	No
Sustainability target	Silver
Heating system	ASHPs only
Capex extent	Heating system installation
Capex source	Developer’s estimates
Opex	Developer’s estimates
Counterfactual	Shared biomass (costed in feasibility study)

Table 31: Project 6 overview

Unit	1	2	3	4	5	6	7	8
Description	2-bed terrace	2-bed WC semi	3-bed semi	4-bed semi	1-bed flat	1-bed WC flat	2-bed flat	2-bed flat
Count	111	16	81	18	27	13	31	3
Footprint (m^2)	89	95	106	122	52	69	77	97.5
Heat demand	2790	3047	3045	3125	2309	2431	2601	2707
Heat demand per m^2	31.3	28.7	25.0	40.6	44.4	35.2	26.7	28.5
Installation capex	£4,944	£4,944	£5,933	£5,933	£5,933	£5,933	£5,933	£5,933
Network capex	Considered negligible							
Total capex	**£4,944**	**£4,944**	**£5,933**	**£5,933**	**£5,933**	**£5,933**	**£5,933**	**£5,933**
Capex per m^2	£55.6	£46.6	£48.6	£77.0	£114.1	£86.0	£60.8	£62.4
Est. opex	£368	£402	£404	£412	£305	£321	£345	£357
Est. opex per m^2	£4.1	£3.8	£3.3	£5.4	£5.9	£4.7	£3.5	£3.8
Alt capex	**£3,093,400 for whole site (approx. £10,300 per unit)**							
Alt capex per m^2	£115.7	£97.2	£84.4	£133.8	£198.1	£149.3	£105.6	£108.4
Est. alt opex	£310	£338	£340	£347	£257	£270	£290	£300
Est. alt per m^2	£3.5	£3.6	£3.2	£2.8	£4.9	£3.9	£3.8	£3.1

Table 32: Project 6 costs per unit

Project 7

An overview of Project 7 is provided in Table 33, and per-unit data in Table 34.

Metric	Information
Location	Angus
Unit count	10
Unit types	1
Progress	Completed
On-gas grid	No
Section 75	Yes
Sustainability target	SAP: 81 (Project set up before the introduction of current standards)
Heating system	ASHPs only
Capex extent	Heating system installation
Capex source	Contractor’s actual costs
Opex	Estimates provided
Alternative	Gas boilers

Table 33: Project 7 overview

<table>
<tr><th>Unit</th><th>1</th></tr>
<tr><td>Description</td><td>3-bed semi</td></tr>
<tr><td>Count</td><td>10</td></tr>
<tr><td>Footprint (m^2)</td><td>100m^2</td></tr>
<tr><td>Heat demand</td><td>3571</td></tr>
<tr><td>Heat demand per m^2</td><td>35.7</td></tr>
<tr><td>Equipment capex</td><td rowspan="2">£10,738</td></tr>
<tr><td>Labour capex</td></tr>
<tr><td>Network capex</td><td>Not considered</td></tr>
<tr><td>Other heating capex</td><td>N/A</td></tr>
<tr><td>Total capex</td><td>£10,738</td></tr>
<tr><td>Capex per m^2</td><td>£107</td></tr>
<tr><td>Est. opex</td><td>£500</td></tr>
<tr><td>Est. opex per m^2</td><td>£5.0</td></tr>
<tr><td>Alt capex</td><td>£2,944</td></tr>
<tr><td>Alt capex per m^2</td><td>£29</td></tr>
<tr><td>Est. alt opex</td><td>£421</td></tr>
<tr><td>Est. alt per m^2</td><td>£4.2</td></tr>
</table>

Table 34: Project 7 costs per unit

Project 8

An overview of Project 8 is provided in Table 35. A per-unit table has not been provided because the project is at an early stage and has not been costed in detail yet.

Metric	Information
Location	Scottish Borders
Unit count	4
Unit types	Not yet established
Progress	Preconstruction
On-gas grid	Yes
Section 75	No
Sustainability target	Silver with Gold aspects
Heating system	ASHPs and MVHR
Capex extent	Heating system installation
Capex source	Housing associations' previous projects
Opex	Not yet established
Alternative	No alternative considered

Table 35: Project 8 overview

Project 9

An overview of Project 9 is provided in Table 36. A per-unit table has not been provided because the project contact was not able to share any cost data.

Metric	Information
Location	Highland
Unit count	14
Unit types	5
Progress	Pre-construction
On-gas grid	No
Section 75	No
Sustainability target	Bronze
Heating system	Air to Water heat pumps; Air to Air heat pumps
Capex extent	Not provided
Capex source	Not provided
Opex	Not provided

Table 36: Project 9 overview

Project 13

An overview of Project 13 is provided in Table 37, and per-unit data in Table 38. Notably, this project is the only one to date to have considered the impact of heating systems on network costs. The alternative capex in Table 38 includes an equal share of the £107k cost for the LPG system infrastructure.

Solar PV has been included as part of the heating system in the tables because the project's opex and capex figures include the impact of this technology. (This is included in the 'Other Capex' row in Table 38.)

Metric	Information
Location	Highland
Unit count	117 (87 with individual ASHP systems)
Unit types	9
Progress	Pre-construction
On-gas grid	No
Section 75	No
Sustainability target	Silver
Heating system	ASHPs, rooftop PV and Sunamp heat batteries
Capex extent	Installation of heating system
Capex source	Contractor's quotation
Opex	Estimates provided
Alternative	LPG

Table 37: Project 13 overview

Unit	1	2	3	4	5	6	7	8
Description	2-bed semi (A)	2-bed semi (B)	3-bed semi (A)	3-bed semi (B)	4-bed det.	2-bed bungalow	3-bed bungalow	2-bed cottage flat
Count	20	10	24	8	7	4	2	12
Footprint (m^2)	92.1	92.1	103	103	117	89	108.0	80.3
Heat demand	2570	2570	2730	2750	3580	3064	3914	2230
Heat demand per m^2	27.9	27.9	26.5	26.7	30.6	34.4	36.2	27.8
Installation capex	£6,672	£6,672	£6,672	£6,672	£6,672	£6,672	£6,672	£6,672
Network capex	Additional £79,806 (£682 per home)							
Sunamp + PV capex	£4,346	£4,346	£4,728	£4,346	£5,603	£4,728	£4,728	£3,955
Total capex	**£11,700**	**£11,700**	**£12,082**	**£11,700**	**£13,119**	**£12,082**	**£12,082**	**£11,309**
Capex per m^2	£127.0	£127.0	£117.3	£113.6	£112.1	£135.7	£111.9	£140.8
Est. opex	£244	£244	£239	£241	£352	£287	£298	£170
Est. opex per m^2	£2.7	£2.7	£2.3	£2.3	£3.0	£3.2	£2.8	£2.1
Alt capex	**£9,875**	**£9,875**	**£10,235**	**£10,375**	**£11,835**	**£11,235**	**£11,735**	**£11,015**
Alt capex per m^2	£107.2	£107.2	£99.4	£100.7	£101.1	£126.2	£108.7	£137.2
Est. alt opex	**£371**	**£371**	**£389**	**£389**	**£588**	**£501**	**£466**	**£323**
Est. alt per m^2	£4.0	£4.0	£3.8	£3.8	£5.0	£5.6	£4.3	£4.0

Table 38: Project 13 costs per unit

Project 14

An overview of Project 14 is provided in Table 39. A per-unit table has not been provided as this project contact was not able to share any cost data.

Metric	Information
Location	Glasgow City
Unit count	2
Unit types	1
Progress	Complete
On-gas grid	Yes
Section 75	No
Sustainability target	Platinum
Heating system	ASHPs, MVHR and Sunamp heat batteries
Capex extent	Not provided
Capex source	Not provided
Opex	Not provided
Alternative	Gas

Table 39: Project 14 overview

Project 15

An overview of Project 15 is provided in Table 40, and per-unit data in Table 41. Notably, this is the only project to include solar thermal hot water generation, which has been denoted as the ‘Other Capex’ costs in Table 41.

Metric	Information
Location	Dumfries & Galloway
Unit count	5
Unit types	3
Progress	Under construction
On-gas grid	No
Section 75	No
Sustainability target	Silver
Heating system	ASHPs, MVHR and solar thermal hot water generation
Capex extent	Heating and hot water system installation
Capex source	Quantity surveyor’s estimates
Opex	From SAP reports
Alternative	None considered

Table 40: Project 15 overview

Unit	1	2	3
Description	2-bed semi	3-bed semi	2-bed amenity bungalow
Count	2	2	1
Footprint (m^2)	87.0	101	69
Heat demand	1215	1044	1120
Heat demand per m^2	14.0	10.3	16.2
Equipment capex	**£10,457**	**£10,457**	**£10,457**
Labour capex			
Network capex	Not considered		
Other heating capex	£3,680	£3,680	£3,680
Total capex	**£14,137**	**£14,137**	**£14,137**
Capex per m^2	£162	£140	£205
Est. opex	£199	£171	£183
Est. opex per m^2	£2.3	£1.7	£2.7

Table 41: Project 15 cost per unit

B3. Air Source Heat Pumps (shared)

Project 16

An overview of Project 16 is provided in Table 42. A per-unit table has not been provided because the project is at an early stage and has not been costed in detail yet.

Metric	Information
Location	Scottish Borders
Unit count	21
Unit types	Not yet established
Progress	Pre-construction
On-gas grid	Yes
Section 75	No
Sustainability target	Silver with Gold aspects
Heating system	Shared ASHPs with heat interface units in each flat
Capex extent	Not yet established
Capex source	Not yet established
Opex	Not yet established
Alternative	No alternative considered

Table 42: Project 16 overview

Project 17

An overview of Project 17 is provided in Table 43. A per-unit table has not been provided because the project is at an early stage and has not been costed in detail yet.

Metric	Information
Location	City of Edinburgh
Unit count	41
Unit types	Not yet established
Progress	Pre-construction
On-gas grid	Yes
Section 75	No (although development will have non-social let flats)
Sustainability target	100% improvement versus Silver (considered to define ‘Net Zero’)
Heating system	Shared ASHPs with heat interface units in each flat
Capex extent	Not yet established
Capex source	Not yet established
Opex	Not yet established

Metric	Information
Alternative	Alternatives considered but these will not be costed

Table 43: Project 17 overview

Project 13 (1-bed flats)

An overview of Project 13 is provided in Table 37, within the individual ASHP section, as the majority (87 of 117 units) incorporate individual systems. However, the development has 30 one-bed flats which are served by five separate communal ASHP systems, one per block.

Costs for these systems are presented in Table 44 below.

Unit	1
Description	1-bed flats, 5 blocks of 6
Count	30
Footprint (m^2)	48.6
Heat demand	1532
Heat demand per m^2	31.5
Installation capex	£8,857
Network capex	£682
Sunamp + PV capex	£4,017
Total capex	**£13,556**
Capex per m^2	£278.9
Est. opex	£150
Est. opex per m^2	£3.1
Alt capex	**£11,015**
Alt capex per m^2	£226.6
Est. alt opex	**£251**
Est. alt per m^2	£5.2

Table 44: Project 13 (1-bed flats) project costs per unit

B4. Ground Source Heat Pumps (Shared)

Project 18

An overview of Project 18 is provided in Table 45, and per-unit data in Table 46. The capex for the GSHP system was provided as a single cost for the whole development.

Metric	Information
Location	West Lothian
Unit count	16 (plus one staff building)
Unit types	1
Progress	Pre-construction
On-gas grid	Yes
Section 75	No
Sustainability target	Silver
Heating system	Shared GSHPs loop with individual heat pumps, underfloor heating
Capex extent	Shared GSHPs loop and individual heat pump installation
Capex source	Quantity Surveyor's estimates
Opex	Estimated by Mechanical Consultants
Alternative	Direct electric heaters (with solar PV to pass SAP)

Table 45: Project 18 overview

Unit	1
Description	1-bed terrace
Count	16
Footprint (m^2)	47.7
Heat demand	2,857
Heat demand per m^2	60
Installation capex	**£10,871**
Network capex	Not considered
Other heating capex	N/A
Total capex	**£10,871**
Capex per m^2	£228
Est. opex	£400
Est. opex per m^2	£8.4
Alt capex	**£4,659** (inclusive of solar PV)
Alt capex per m^2	£97.7
Est. alt opex	£1,400

Unit	1
Est. alt per m^2	£29.4

Table 46: Project 18 costs per unit

Project 19

An overview of Project 19 is provided in Table 47, and per-unit data in Table 48.

Metric	Information
Location	City of Edinburgh
Unit count	84
Unit types	5
Progress	Under construction
On-gas grid	Yes
Section 75	Yes
Sustainability target	Aspect Silver Levels 1 and 2
Heating system	Shared GSHPs loop with individual heat pumps, underfloor heating
Capex extent	Shared GSHPs loop and individual heat pump installation
Capex source	Actual costs
Opex	Estimated by developer
Alternative	Gas boilers

Table 47: Project 19 overview

Unit	1	2	3	4	5
Description	2-bed terrace	2-bed end	3-bed terrace	3-bed end	4-bed semi
Count	16	16	34	10	8
Footprint (m^2)	82	82	97	97	125
Heat demand	1674	1674	1980	1980	2552
Heat demand per m^2	20.4	20.4	20.4	20.4	20.4
Equipment capex / Labour capex	**£11,500**	**£11,500**	**£11,500**	**£11,500**	**£11,500**
Network capex	Not considered				
Other heating capex	N/A				
Total capex	**£11,500**	**£11,500**	**£11,500**	**£11,500**	**£11,500**
Capex per m^2	£140	£119	£119	£92	£92
Est. opex	£88	£88	£104	£104	£135
Est. opex per m^2	1.1	1.1	1.1	1.1	1.1

Unit	1	2	3	4	5
Alt capex	**£4,000**	**£4,000**	**£4,000**	**£4,000**	**£4,000**
Alt capex per m^2	49	41	41	32	32
Est. alt opex	£118	£118	£139	£139	£180
Est. alt per m^2	1.4	1.4	1.4	1.4	1.4

Table 48: Project 19 costs per unit

B5. Biomass (shared)

Project 20

An overview of Project 20 is provided in Table 49, and per-unit data in Table 50. Rather than a purpose-built biomass plant for the housing development, the heat source for this project is an industrial scale biomass combined heat and power plant. The capex for the system in this project was provided as a single cost for the whole development, so the figures presented below assign an equal portion of the total cost to each of the units.

Metric	Information
Location	Fife
Unit count	85
Unit types	11
Progress	Under construction
On-gas grid	Yes
Section 75	Yes
Sustainability target	Silver
Heating system	Shared biomass heating from Markinch biomass plant
Capex extent	District heating network and heat interface units in each property
Capex source	Actual costs
Opex	Central estimates provided
Alternative	Gas boilers – not costed

Table 49: Project 20 overview

Unit	1	2	3	4	5
Description	2-bed terrace	3-bed terrace (A)	3-bed terrace (B)	2-bed WC semi	2-bed semi
Count	28	15	11	4	2
Footprint (m^2)	83.2	93	116.8	79.8	95.3
Heat demand	5,410	6,047	7,594	5,189	6,196
Heat demand per m^2	65	65	65	65	65
Installation capex	£8,837	£8,837	£8,837	£8,837	£8,837
Network capex	Inherent to above costs				
Other heating capex	N/A				
Total capex	**£8,837**	**£8,837**	**£8,837**	**£8,837**	**£8,837**
Capex per m^2	£106	£95	£76	£111	£93
Est. opex	£139	£155	£195	£133	£159

Unit	1	2	3	4	5
Est. opex per m²	£1.67	£1.67	£1.67	£1.67	£1.67

Table 50: Project 20 costs per unit (A)

Unit	6	7	8	9	10	11
Description	4-bed det.	4-bed WC semi	4-bed semi	5-bed detached	2-bed cottage flat	2-bed WC cottage flat
Count	2	4	2	5	6	6
Footprint (m²)	112.8	98.1	122.2	120	83.8	79
Heat demand	7,334	6,378	7,945	7,802	5,449	5,137
Heat demand per m²	65	65	65	65	65	65
Equipment capex	£8,837	£8,837	£8,837	£8,837	£8,837	£8,837
Labour capex						
Network capex	Inherent to above costs					
Other heating capex	N/A					
Total capex	**£8,837**	**£8,837**	**£8,837**	**£8,837**	**£8,837**	**£8,837**
Capex per m²	£78	£90	£72	£74	£105	£112
Est. opex	£188	£164	£204	£200	£140	£132
Est. opex per m²	£1.67	£1.67	£1.67	£1.67	£1.67	£1.67

Table 51: Project 20 costs per unit (B)

Project 21

An overview of Project 21 is provided in Table 52. A per-unit table has also been provided.

Metric	Information
Location	North Ayrshire
Unit count	123
Unit types	15
Progress	Under construction
On-gas grid	Yes
Section 75	No
Sustainability target	Aspect Silver Levels 1 and 2
Heating system	Shared biomass heating
Capex extent	DHN installation costs (inc. back-up system)
Capex source	Actual costs (averaged from development total)
Opex	Estimates Provided
Alternative	Gas DHN

Table 52: Project 21 overview

Unit	6	7	8	9	10
Description	2-bed bungalow (A)	2-bed bungalow (B)	2-bed WC bungalow	2-bed house (A)	2-bed house (B)
Count	5	7	4	13	13
Footprint (m^2)	63	63	63	88	84
Heat demand	4,111	3,889	4,111	4,778	4,222
Heat demand per m^2	65	62	65	54	50
Installation capex	£11,355	£11,355	£11,355	£11,355	£11,355
Network capex	Inherent to above costs				
Other heating capex	N/A				
Total capex	**£11,355**	**£11,355**	**£11,355**	**£11,355**	**£11,355**
Capex per m^2	£245	£177	£206	£237	£183
Est. opex	£110	£150	£160	£145	£175
Est. opex per m^2	£2.38	£2.34	£2.91	£3.02	£2.81
Alt capex	**£3,015**	**£3,015**	**£3,015**	**£3,015**	**£3,015**
Alt capex per m^2	65.1	47.0	54.8	62.8	48.5

Unit	6	7	8	9	10
Est. alt opex	£110	£150	£160	£145	£175
Est. alt per m^2	£2.38	£2.34	£2.91	£3.02	£2.81

Table 53: Project 21 costs per unit (A)

Unit	6	7	8	9	10
Description	2-bed bungalow (A)	2-bed bungalow (B)	2-bed WC bungalow	2-bed house (A)	2-bed house (B)
Count	5	7	4	13	13
Footprint (m^2)	63	63	63	88	84
Heat demand	4,111	3,889	4,111	4,778	4,222
Heat demand per m^2	65	62	65	54	50
Installation capex	£11,355	£11,355	£11,355	£11,355	£11,355
Network capex	Inherent to above costs				
Other heating capex	N/A				
Total capex	**£11,355**	**£11,355**	**£11,355**	**£11,355**	**£11,355**
Capex per m^2	£245	£177	£206	£237	£183
Est. opex	£110	£150	£160	£145	£175
Est. opex per m^2	£2.38	£2.34	£2.91	£3.02	£2.81
Alt capex	**£3,015**	**£3,015**	**£3,015**	**£3,015**	**£3,015**
Alt capex per m^2	47.9	47.9	47.9	34.1	35.7
Est. alt opex	£185	£175	£185	£215	£190
Est. alt per m^2	£2.94	£2.78	£2.94	£2.43	£2.25

Table 54: Project 21 costs per unit (B)

Unit	11	12	13	14	15
Description	3-bed house	3-bed WC house	4-bed house (A)	4-bed house (B)	4-bed bungalow
Count	20	1	3	1	2
Footprint (m^2)	96	119	108	112	130
Heat demand	4,667	5,778	5,556	5,778	6,444
Heat demand per m^2	49	49	51	52	50
Installation capex	£11,355	£11,355	£11,355	£11,355	£11,355
Network capex	Inherent to above costs				
Other heating capex	N/A				
Total capex	**£11,355**	**£11,355**	**£11,355**	**£11,355**	**£11,355**
Capex per m^2	£135	£119	£96	£105	£101
Est. opex	£190	£210	£260	£250	£260

Unit	11	12	13	14	15
Est. opex per m^2	£2.25	£2.20	£2.19	£2.31	£2.32
Alt capex	**£3,015**	**£3,015**	**£3,015**	**£3,015**	**£3,015**
Alt capex per m^2	31.5	25.4	27.9	26.9	23.2
Est. alt opex	£210	£260	£250	£260	£290
Est. alt per m^2	£2.20	£2.19	£2.31	£2.32	£2.23

Table 55: Project 21 costs per unit (C)

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