Research into Electricity Network Constraints and the 2024 New Build Heat Standard: Final Report

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Research into Electricity Network Constraints and the 2024 New Build Heat Standard: Final Report

A report for the Scottish Government

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Executive summary

The 2024 New Build Heat Standard will require all new homes in Scotland to use heating systems which produce zero direct emissions at the point of use from 2024 onwards. This change will have an impact on the energy infrastructure costs for new domestic developments. The Scottish Government commissioned Ricardo Energy & Environment (Ricardo) to undertake research into the network constraints issues associated with the electrification of heat for domestic new build developments.

The project aimed to address the following questions:

What are the main business models, contractual arrangements, revenue streams and methods of apportioning risk for the installation and operation of new energy infrastructure? How are these decisions made?	What are the costs for network infrastructure for various new build case studies? Who pays these costs, and how are they passed onto house buyers or tenants?	How do these costs compare between developments with fully electrified heating and traditional heating solutions? How does this vary between contexts, technologies and locations? What is the impact of other low carbon technologies like electric vehicles?
How are decisions made regarding the potential trade-offs between building efficiency, heating requirements and electricity network connection costs?	What are the findings into innovative projects or activities where technology has been optimised to minimise network costs?	What are the specific considerations for stakeholders in relation to the 2024 standards and network constraints? How do the answers differ between a development using an IDNO and one where the network will be adopted by the local DNO?

The project methodology included three work packages:

Literature Review

Leveraged existing, published documents to inform the answering of the project questions, and provided context and data for the stakeholder engagement and the technical modelling.

Focused on four high level topics: standards, industry documentation, heating technology options and

Stakeholder Engagement

Gained an understanding of the processes, underlying business cases, decision factors, and how this might be impacted by the choice of heating technology.

Stakeholder categories included developers, Independent Distribution Network Operators

Technical Modelling

Explored the connection costs for three modelled case study examples:

Private housing development:
300 homes in the North Glasgow area with a strong local electrical network.

Social housing development:
60 houses and flats in the Dunfermline area, with a

The following sections address the key project questions.

Business models for establishing energy assets for new developments

The main roles and business models are described in the table below:

Description	Business driver
Housing developer: Within this project, the term 'housing developer' is used for the organisation or collection of organisations responsible for buying and developing land for housing	Private housing developers aim to make a profit through sale or rent of the properties. As sale or rental prices are driven by the wider market, an increase in development cost generally reduces profit. Affordable housing is developed with the intention of meeting a need for housing. The cost of development is recuperated through rental.
Distribution Network Operators (DNOs) A DNO owns, operates and maintains electricity distribution networks in one or more designated geographic regions in GB. They provide connections to their networks for new developments. New electricity network assets can be built by either a DNO or an ICP.	DNOs get their funding through the Distribution Use of System (DUoS) charge, which is part of every electricity customers' bills. DUoS charges are regulated by Ofgem. DNOs have a licence obligation to respond to connection requests with quotes which represent the least cost option overall.
Independent Distribution Network Operators (IDNOs) An IDNO owns and operates a local electricity distribution network, typically serving new developments within the DNO network, built by an ICP.	IDNOs are funded through DUoS charges from connected customers. Many IDNOs also manage other utilities (e.g. gas, communications, wastewater). IDNOs can offer an 'asset value' payment, which is payable to the developer for the adoption of a network. This asset value is determined through balancing the revenue potential of the network with the competition to adopt.
Independent Connection Provider (ICP) An ICP can provide design and installation of new infrastructure for developments. Once built, the network must be adopted by a network operator. Alterations to existing DNO networks must be built by the DNO.	ICPs are contracted and funded by the developer to design and install the equipment. They cannot operate networks and must set up a contractual arrangement with an adopting IDNO or DNO. ICPs may have in house or partnered IDNOs that they generally choose to adopt their infrastructure, and the ICP and IDNO functions can be coordinated.

The process for establishing energy infrastructure can take two main forms:

- **Process includes the developer and DNO:** Where the developer directly engages the DNO to supply the energy infrastructure and the connection. In this case, the DNO will produce a design and quote for the installation, and if the developer accepts this quote, a formal agreement is set up. Once built, the DNO operates the network as part of their wider network.

- **Process includes the developer, ICP and DNO / IDNO:** The developer may engage an ICP through existing partnerships or through open tender arrangements. The ICP selects a network operator (IDNO or IDNO) to adopt the assets after construction, interfaces with the DNO to provide a connection to their network and designs and builds any new energy infrastructure.

Engaging an ICP to provide the work involves more parties and can be more complex. However, this option provides the developer the opportunity to seek out the most cost-effective option for providing connections. They may issue a tender, receiving submissions from multiple ICPs and comparing this with a quote provided by the DNO. The ICP quote may include the cost of connection (gained through a connection request to the DNO), and an asset value payment from an IDNO, as well as the cost to install the new assets. The selection of the provider is generally driven by cost or through existing relationships with an ICP or IDNO.

Cost associated with network infrastructure for new build examples

Costs associated with establishing energy infrastructure are highly variable between developments, mainly driven by:

- **Size of the energy load:** The maximum demand expected to be drawn over the whole development, to which the energy infrastructure must be designed.
- **Distance and complexity of the route:** A longer route between the development site and the point of connection on the energy network, or the inclusion of waterway or carriageway crossings, can increase costs significantly.
- **Status of adjacent energy network:** Available capacity on the energy system to support new loads, and the work required to release additional capacity, impacts cost to connect.

The modelled case studies show illustrative examples of infrastructure costs for connection of traditional electricity and gas networks, shown below.

Private housing development:
300 home development connecting to an unconstrained network. Infrastructure includes cabling over a 30m route, a substation, and service connections to each property.

Electricity infrastructure: £262k to £586k
Gas infrastructure: £90k to £150k

Social housing development
60 home development connecting to a highly constrained network, although this development does not exceed the available capacity. Infrastructure includes cabling over a 100m route and service connections to each property.

Electricity infrastructure: £49k to £105k
Gas infrastructure: £54k to £72k

Small scale rural development
10 home development connecting to a rural network. Infrastructure includes overhead line route of 200m, a pole mounted transformer and service connections to each property.

Electricity infrastructure: £40k to £86k
Gas infrastructure: £9k to £12k

The costs are shown as broad ranges, as costs are highly dependent on site specific circumstances . There are several notable costs that are not included in the scope of this project, such as the costs of the technology appliance, installation costs and the operational costs of the resulting heating system. These costs are important to consider when comparing costs of heating technologies.

Impact of fully electrified heat technologies

Moving to an electric heating technology increases the size of the electricity load across that development, in some cases requiring additional electricity network infrastructure. However, gas assets are no longer required.

The modelled case study findings are given below:

Total electricity infrastructure costs for different heating technology choices

Private housing development: As the network is unconstrained, the additional load associated with electrification of heat can be accommodated without significant additional infrastructure. The range of costs reflect the onsite infrastructure needed to support additional load.	Heat pumps: £326k to £763k Storage heaters: £381k to £913k District heating: £269k to £607k
Social housing development As a highly constrained network, moving heat load to electricity results in the need for significant and costly infrastructure. As the it is a developing area, reinforcement costs are apportioned and only £400k to £650k is charged to the developer.	Heat pumps: £4.2m to £6.4m Storage heaters: £4.2m to £6.4m District heating: £4.2m to £6.4m
Small scale rural development The variation in demand across different heating technologies is not enough to result in additional network infrastructure required, and as a result, the electricity infrastructure costs do not change across the heating technologies.	Heat pumps: £40k to £86k Storage heaters: £40k to £86k District heating: £40k to £86k

Apportioning costs between stakeholders

The table below shows how costs are shared and apportioned between stakeholders.

	What they pay	What they are paid
Developers	Pays the DNO/ICP to develop new energy infrastructure for sole use by the development. Pays the DNO a proportion of the costs for assets that are likely to be used by other connections or other network customers.	May be paid an asset value by an IDNO to help offset the infrastructure costs. This may be incorporated into the quoted infrastructure costs Recover costs through sale or rent of properties.
DNOs	Costs incurred from designing and installing network infrastructure. Where the DNO operates the new assets; incur operational costs on an ongoing basis.	Developer pays for all assets that are for sole use by the development, and a proportion of the assets that are likely to be used by other connections. Remaining reinforcement costs are socialised – recovered from all connected customers through their bills. Ongoing revenue recovered from all connected customers through their bills.
IDNOs	Where an IDNO adopts the assets: May pay an asset value to the developer to adopt the assets. Incur operational costs on an ongoing basis.	Ongoing revenue recovered from all connected customers through their bills.

ICPs	Where an ICP installs new infrastructure: Costs incurred from designing and installing new infrastructure.	Developer pays for the development of new energy infrastructure for sole use by the development.

The housing developer takes on the majority of the costs of the energy infrastructure for a development. If the energy assets are being adopted by an IDNO, the developer may be provided an asset value to offset their costs. Any remaining costs must be covered by the sale or rental value of the properties as a decrease in profit or where possible, an increase in sale or rental price. However, the sale or rental prices are generally driven by the wider market.

Costs adopted by the DNO, through apportioned network reinforcement costs, are socialised through an increase in the Distribution Use of System (DUoS) charges to their connected customers. Due to the number of customers, the impact on individual customers is negligible.

Key drivers for decision making

There are several key decision points during the process to establish electricity network infrastructure for new housing developments. The most relevant for this project include:

Choice of parties to engage in the design and build

Who decides: Developer

Key drivers:

- Business case and convenience
- The majority of developments include an ICP / IDNO, due to the competitive process and the potential to offer an asset value

Selection of heating technology

Who decides: Developer

Key drivers:

- Meeting building regulations
- Cost to install, operate and maintain
- Experience and understanding
- User experience / desirability

Choice of building fabric and other technologies

Who decides: Developer

Key drivers:

- Energy efficiency requirements of the building regulations
- Commercial case around desirability of the home for potential customers

Design of the energy infrastructure

Who decides: DNO or ICP

Key drivers:

- Energy requirements of the development
- Meeting the design standards of the adopting network operator

Innovative projects that might minimise infrastructure costs

Innovative projects have built experience in the electrification of heat and enhanced understanding about technologies and the effects they may have on the electricity network. The main topics include:

- **Identifying opportunities for electrification of heating:** There is no one-size-fits-all solution for heat decarbonisation. This must be considered at the local level as well as the national level. There are projects underway to identify the locations best suited to rolling out of heat technology.
- **Understanding zero emissions heating options:** A key barrier is a lack of understanding of the zero emission technology and its impact on the network. There are several initiatives that will build this understanding, allowing developers to build confidence in the technologies and ICPs and DNOs to develop more informed and efficient network designs.
- **Energy management:** Several projects identified opportunities to manage flexible electricity demand, such as heat pumps, storage and EV charging, to minimise the impact on the electricity network. This can be used to reduce the size of the required connection and to provide services to the wider electricity system, providing an additional revenue.

Key considerations for stakeholders in relation to the 2024 standards

An important finding of the project has been the insights into the key considerations from the perspectives of each of the key stakeholder groups. These are summarised below.

Key considerations for developers

- Developers need to understand the choice of zero emissions heating technologies that meet the new requirements, and the associated cost and practical implications.
- A number of barriers were flagged to the adoption of new heating solutions, including a lack of experience and confidence in the technology, a perception of higher costs, access to and maturity of the supply chain, operational costs and user experience.
- Developers are also concerned about the transition to the new 2024 standards, particularly regarding projects that are currently underway and the impact the new standards will have on business cases for established projects.

Key considerations for DNOs, IDNOs & ICPs

- Different low carbon technologies present different challenges and opportunities to the design and operation of energy infrastructure. However, the practical operation of these technologies and the implication on the network is not fully understood, leading to conservative or inconsistent infrastructure design. Some of this uncertainty is being addressed by innovative projects and data collection, the learning from which will be particularly valuable if the findings are combined and best practice is shared to ensure a consistent, optimised approach across stakeholders.
- IDNOs and ICPs need to be aware of the potential of innovative approaches and technologies that may support connection and operation of local development energy infrastructure, such as energy management and managed connections, and work with developers and the DNO to support adoption.
- As gas networks may no longer be needed for new developments with electric heating, there is a potential reduction in revenue for the ICP and IDNO for involvement in a given project. However, this may be countered if district heating technologies are adopted.

Key considerations for homeowners / occupiers

- The key consideration for owners / occupiers is the effectiveness of the heating technology, including ease of use, resulting comfort levels and impacts on energy bills.
- User education and ease of use of new appliances may be necessary to support effective and efficient operation to maximise user comfort for minimal operation costs.
- Operational costs of the system should be considered when installing the heating technology; there is a danger that lower installation costs of resistive heating technologies may mean that homes are expensive to heat.

Conclusions

The project outcome has been to build a greater understanding of the network constraints issues associated with the electrification of heat for domestic new build developments, through literature review, stakeholder engagement and modelled case studies. The key learning points include:

- **The impact of adopting zero emissions heating in new developments on the energy infrastructure costs is variable** based on factors including the selection of heating technology, the wider design of the development, the location of the development site, and the available capacity and status of the existing local electricity network.
- **It is important to consider all costs associated with the heating technology**, beyond the energy infrastructure, including the costs of the technology appliance, and the installation and operational costs of the resulting heating system.
- **It is important to consider buildings and developments holistically.** The heating technology cannot be considered in isolation; building fabric has a significant impact on the heating load; understanding the non-heating demand

is important to understand the network impact and, where there are network constraints, the mitigation opportunities.

- **It is increasingly important that stakeholders are open to innovative solutions** and work closely together from an early stage in complex developments. If all stakeholders work together on a development, information can be shared and used in design decisions, and ideas around flexibility, optimisation and innovation can be explored.
- **There are barriers to the adoption of zero emissions heating technologies beyond infrastructure costs**, including a lack of understanding, skills and supply chain relationships, and concerns about user acceptance and usability. It is important to consider how to best support the transition towards successful adoption.

Recommendations for next steps

It is recommended that the next steps following this project include

- **Combine learning from related projects:** Relevant projects and research should be combined and synthesised into an overarching picture to inform policy and implementation.
- **Support the transition to zero emissions heating:** Consulting on the issues, barriers and solutions towards the adoption of renewable or zero emissions heating in new homes and developing and promoting best practice.
- **Engage stakeholders in collaboration, innovation and best practice:** Promoting and encouraging collaboration, and sharing best practice will best equip stakeholders to successfully transition to zero emissions heating technologies.
- **Further exploration of district heating:** Exploring the barriers, benefits and best practice for district heating.
- **Explore barriers and solutions for adoption of retrofit zero emissions heating:** The adoption of decarbonised heat across the retrofit housing stock is a significant challenge, with very different barriers and solutions. Scottish Government could build knowledge in this area to inform policy and implementation to support this transition.

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Glossary

Abbreviation	Definition
ADMD	After Diversity Maximum Demand
DNO	Distribution Network Operator
DUoS	Distribution Use of System
EPC	Energy Performance Certificate
EV	Electric Vehicle
GB	Great Britain
GDN	Gas Distribution Network
IDNO	Independent Distribution Network Operator
ICP	Independent Connection Provider
IGT	Independent Gas Transporters
LED	Light Emitting Diode
SAP	Standard Assessment Procedure
SCR	Significant Code Review
SPEN	Scottish Power Energy Networks
SSEN	Scottish and Southern Electricity Networks
TCR	Targeted Charging Review

1 Introduction

1.1 Project context

The 2024 New Build Heat Standard will require all new homes in Scotland to use heating systems which produce zero direct emissions at the point of use from 2024 onwards. Many of the established zero emissions approaches to space and water heating use the electricity network, which in itself has been significantly decarbonised in Scotland through the growth in renewable generation. Therefore, electrically powered heating will play an important part in decarbonising heating in Scotland.

Space and water heating demand make up a significant proportion of the energy requirements of a home. Meeting this energy requirement through electricity rather than the gas network will require additional electricity network capacity, which will have cost implications for the new developments and can change the business models that will be adopted to develop housing and establish energy infrastructure.

The Scottish Government commissioned Ricardo Energy & Environment (Ricardo) to undertake research into the network constraints issues associated with the electrification of heat for domestic new build developments. The focus of the work is on connection costs for these developments, how the cost is defined, and apportioned to the relevant stakeholder. It is important for the cost implications of the decarbonisation of heat to be understood, so that the Scottish Government, the building developers, and the energy sector can take these into account as part of their business plans when considering the implementation of the 2024 standards.

This report provides the results of the research undertaken by Ricardo to support with the Scottish Government's implementation of the 2024 New Build Heat Standard.

1.2 Requirements of the project

The purpose of the assessment was to address the key questions shown in

Table 1-1 below. The sections of this document where each question is addressed is also referenced.

Table 1-1 Project questions and the sections within the document which addresses them (note – terms such as DNO and IDNO are defined in more detail in Section 3.1)

Project question	Document section
What are the main business models for establishing energy network assets for new developments? Including contractual arrangements, revenue streams, apportioning risk and ownership, and the key decision factors.	**Section 3**
What is the total cost associated with network infrastructure for various new build examples? How is this apportioned between housing developers, IDNOs, DNOs, home buyers, tenants, and the general public?	**Section 4**
How do these costs compare between a 'traditional'/business as usual development and a fully electrified development for heat requirements?	**Section 4**
How are decisions made, and by whom, regarding the potential trade-offs between building design, fabric efficiency and onsite generation and storage technologies on the one hand, and electricity network connection/upgrade costs on the other?	**Section 3**
Are there any examples of innovative projects/demonstrators (including international) where technology has been optimised (e.g. smart enabled) to minimise network costs?	**Section 5**
Are there other key considerations for developers, DNOs and IDNOs specifically, in relation to the 2024 standards and network constraints that are not covered in the questions above?	**Section 6**
How do the answers to the previous questions differ between a development using an IDNO and one where the network will be directly adopted by the local DNO?	**Section 3**

2 Methodology

The project was split into three main work packages, which were carried out in parallel:

- **Literature review**
- **Stakeholder engagement**
- **Technical modelling**

These are described below. The outcomes of these work packages were then combined in consideration of the project questions, which are addressed in Sections 3 to 6.

2.1 Literature review

The aim of literature review was to leverage existing published documents to address the project questions (see

Table 1-1) and provide context and data for the stakeholder engagement and technical modelling work packages. The literature review focused on four high level topics: standards, industry documentation, heating technology options and related innovation projects. These are summarised in the following sub-sections.

2.1.1 Standards

Table 2-1 summarises the standards included in this review.

Table 2-1 List of existing and published standards included in the literature review

Resources reviewed	Relevance in the project
EREC G81 Part 1: Framework for new low voltage housing development installations – Design and planning [1]	This document is focused on the requirements on the electricity sector parties to undertake new connections. The key elements relevant to the 2024 New Build Heat Standard include the need to provide 'efficient and co-ordinated system of electricity supply that is economical and safe'. This has implications on the energy infrastructure requirements for developments.
Energy Efficient Scotland Consultation: Making our homes and buildings warmer, greener and more efficient [2]	This document refers to the requirements on housing developers to make buildings more energy efficient. Many of the specific targets will be superseded by the 2024 New Build Heat Standard, which will legislate for new buildings to become more energy efficient and to adopt zero emissions heating from 2024. The methods by which this will be defined are in development.
Building Standards Regulation & Technical Handbook (Domestic) [3]	This document is focused on ensuring that existing and new buildings comply with current building regulations. The energy requirements legislate for homes becoming more energy efficient and to reduce levels of emission by adopting low carbon technology. Many of the energy requirements will be included in the 2024 standard.
Explanation of the SAP Building Regulation requirements [4]	This document refers to the requirements to make homes more sustainable by complying with regulations in place since 2010 and encouraging more sustainability. The Standard Assessment Procedure (SAP) is the methodology used across the industry to ensure homes that are being built meet energy and environmental performance requirements. Levels of performance are defined as Bronze, Bronze Active, Silver, Silver Active and Gold. May of the specific targets will be superseded by the 2024 standards.
2024 New Build Zero Emissions Heat Standard	Information was provided about the new legislation that the Scottish Government are implementing. This is going through

Scoping Consultation [5]	a number of technical consultations. This document was provided directly by the Scottish Government[1].

2.1.2 Industry documentation on connection charging

The Great Britain (GB) Electricity Distribution license requires large licenced energy network operators to produce a connection charging methodology to describe how new connections are designed and how costs are calculated[2]. The information gathered at this stage provided the background knowledge to support discussions with the network operators in the stakeholder engagement task. The sources included are provided in Table 2-2.

Table 2-2 List of connection charging methodologies included in the literature review

Connection methodologies reviewed	Network operator
Connection charging methodology document for connection to Scottish Power's distribution network [6]	Scottish Power Energy Networks (SPEN)
Connection charging methodology document for connection to Scottish and Southern Electricity Networks distribution network [7]	Scottish and Southern Electricity Networks (SSEN)
Connection charging methodology document for connection to GTC's distribution network [8]	GTC (an independent utility provider)

2.1.3 Heating technology options

The study considers commercially mature zero emissions heating technologies that are a likely option for new build domestic developments. Assumptions for heating options have been identified based on the knowledge accumulated from industry experts at Ricardo and from the following sources:

- The SEAI heat pump technology guide for heat pumps and hybrid heat pumps [9]
- The case study of Queens Quay district heating network [10]

2.1.4 Innovative project reviews

The innovation project review focused on projects that involve innovations that could support connection of zero emissions heat technologies as part of new domestic build developments. A list of these projects is provided below. The findings from this review are summarised in Section 5, and each project is described in Appendix A4.

- **Spatial Analysis of Future Electric Heat Demand (SAFEHD)** [11] is a project to develop optimal heat decarbonisation pathways run by SP Energy Networks and SP Distribution.

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[1] *A more detailed technical consultation will be launched in 2021*
[2] *The charging methodology documents are maintained and updated every year*

- **Heat Street** [12] is a project run by UK Power Networks developing an approach to forecasting adoption of energy efficiency measures and low carbon heating solutions.
- **Regional Energy System Optimisation Planning (RESOP)** [13] is developing a whole energy system tool for local councils whilst assessing the impact of those plans and the technologies they use on the local electricity network. The project is being delivered by SSEN.
- **Electrification of Heat Demonstration Projects** [14] aimed to demonstrate the feasibility of large-scale roll-out of heat pumps in GB. E.ON, OVO Energy and Warmworks undertook trials in different areas of GB.
- **Flexible Residential Energy Efficiency Demand Optimisation and Management (Freedom)** [15] was conducted by Western Power Distribution. It demonstrated the feasibility of hybrid heat pumps on the distribution network
- **Cold Start** [16] is investigating the technical challenges of restoration of power with high EV and heat pump penetration. The project is being delivered by UKPN.
- **4D Heat** [17] investigated matching electrified heat demand with times of surplus renewable energy that would otherwise lead to curtailment. It was delivered by SSEN.
- **Northern Isles New Energy Solutions (NINES)** [18] is being run by SSEN and is introducing methods to use energy storage solutions, such as thermal storage, with active network management.
- **Electrical Heat Pathways: Looking Beyond Heat Pumps** [19] is being researched by SSEN into storage heating's place as part of the solution to decarbonise heating.
- **Copenhagen district heating and cooling scheme** [20] is an example of a world-leading district heat system
- **Queens Quay** [10] district heating scheme is an example of an innovative district heating system based in Scotland
- **ENGIE's harmony project** [21] with Enfield Council is an example of district heating system with a modular approach to heat generation

2.2 Stakeholder engagement

The aims of the stakeholder engagement work package were to engage with selected stakeholders in order to explore the processes, decisions and costs involved in establishing energy infrastructure and connections for new domestic development, and the impact of switching to zero emissions heating technologies. The engagement also aimed to collect information and data to inform the technical modelling task. A survey was sent to a group of affordable housing developers.

Table 2-3 below shows the list of stakeholders that were included in the stakeholder engagement process.

Table 2-3 List of stakeholders that were engaged during the stakeholder engagement process. The roles listed refer to the roles that are most relevant to the project. For some of the stakeholders, this role represents only a small part of their business.

Organisation	Role	Engagement
Scottish Power Energy Networks (SSEN)	Electricity network operator, who owns and operates the distribution network in Central & Southern Scotland	Online interview, provision of data, and email discussions
Scottish and Southern Electricity Networks (SPEN)	Electricity network operator, who owns and operates the distribution network in North of Scotland	Online interview, provision of data, and email and telephone discussions
GTC	Independent energy utility who construct, own and operate multi-utility networks across GB	Online interview, provision of data, and email discussions
Last Mile	Independent energy utility who adopts and operates multi-utility networks	Online interview, provision of data, and email discussions
Independent Networks Association (INA)	Independent body which represent the voice of the UK's independent utility providers	Survey response
Energetics	Independent energy connections provider, who constructs multi-utility network infrastructure	Two online interviews, provision of data, and email discussions
Homes for Scotland	Association for housing developers across Scotland	Online discussion and sharing of contacts
CALA Homes	Housing developers of private developments	Online interview, provision of data, and detailed discussions
Angus Housing Association	Housing developers of affordable housing	Online interview, provision of data, and email discussions
5 respondents	Affordable housing developers across Scotland	Survey responses
Mitsubishi Electric	Heat Pump manufacturer	Online interview
Panasonic	Heat Pump manufacturer	Online interview
E.ON	Energy Supplier and Innovation specialists	Online interview, provision of information

Ramboll is an engineering, architecture and consultancy company who have been commissioned by the Scottish Government to undertake a related project; Costs of Zero Carbon Heat Research, which explores the operational costs and other implications of operating alternative heating technologies. Ramboll provided notes from their engagement with stakeholders for a separate project and have provided information about their project approach to enable alignment of the projects.

2.3 Technical model

The aim of the technical modelling task was to explore the connection costs for three case study examples given a range of common zero emissions heating options. The technical model case study assumptions and results are described in Appendix A2.

The case studies were selected to explore the breadth of applications and situations that are of most interest to the Scottish Government, including a range of development sizes, locations, and technologies (heating, EV and solar panels). The case studies were designed to align with the scenarios developed by a separate project commissioned by the Scottish Government; Costs of Zero Carbon Heat Research carried out by Ramboll, which explored the operational costs and other implications of operating alternative heating technologies. It is hoped that aligning the case studies will allow the Scottish Government to gain increased value from each of the projects and their findings.

The technical model methodology was based on the following steps:

- **Define the case study developments:** This included defining the number and size of dwellings on the development, the location of the development compared to the most appropriate electricity network connection point, and the available capacity and status of the nearby electricity network as a whole.
- **Identify required size of electricity system connection:** As well as the location of the development, the costs to provide electricity infrastructure and connection to a development is driven by the required electricity infrastructure size. This is also driven by the number and type of homes to be connected, and the choice of heating technology. The presence of Electric Vehicle (EV) charging infrastructure was also considered.
- **Identify costs to establish the electricity infrastructure for the development:** The costs are based on the connection charging methodology of the network operators and represent a range of likely costs to reflect the uncertainty and site-specific nature of the works.
- **Estimate the gas network counterfactual:** The model results for the electric heating technologies were compared with a counterfactual case of individual property gas boilers. It is noted that this heating technology does not meet the zero emissions requirements of the 2024 New Build Heat standards but provides a comparator for the other modelled technologies. The gas connection size and costs are based on existing project examples provided by during stakeholder engagement.

The project also identified real development examples to provide context and insight. Whilst these examples are not as complete or tailored as the modelled case studies, they provide learning and insight that supports the findings of the rest of the project and the technical modelling activities.

3 Business models for new energy infrastructure

This section presents the key roles and business models that are used today for establishing energy infrastructure for new domestic buildings, the connection process and the key drivers for decision making.

It addresses the project questions around the business models for establishing energy network assets for new developments, how are decisions made and by whom, and the range of differing approaches and stakeholder involvement.

3.1 Key roles and business models

The key roles and organisations that are generally involved in establishing electricity energy infrastructure for new developments are listed in Table 3-1. The table also details the key business driver and revenue stream of each party.

Table 3-1: Key roles and organisations that are generally involved in establishing electricity energy infrastructure for new developments

Role	Description	Business driver
Housing developers	Within this project, the term ‘housing developer’ is generically used for the organisation or collection of organisations responsible for buying and developing land for housing; this includes developers of both private and affordable housing, and can represent a consortium or subcontractor arrangement as well as single organisations (these structures are not explored in this report). The developers who have contributed to this project are CALA Homes and Angus Housing Association, Homes for Scotland who represent over 200 housing developers, and five additional affordable housing associations who responded to a survey.	Private housing developers aim to build their homes at a financial profit, either through sale of the property or retaining the property as a rental asset. Generally, the sale or rental price of the property is driven by the wider market, and so any increase in development cost will be borne by the development company itself. Affordable housing is generally developed with the intention of meeting a need for housing. The cost of development is recuperated through rental of the properties. Often, affordable housing is managed over a large portfolio with standardised rental between locations, potentially taking account of factors such as energy efficiency.

Role	Description	Business driver
Distribution Network Operators (DNOs)	A DNO owns, operates and maintains electricity distribution networks in one or more designated geographic regions in GB. They must hold a distribution licence from the energy regulator Ofgem. The two DNOs operating in Scotland are: • Scottish Power Energy Networks (SPEN): Central & Southern Scotland. • Scottish & Southern Electricity Networks (SSEN): North Scotland. We engaged with both SPEN and SSEN as part of this project.	DNOs get their funding the Distribution Use of System (DUoS) charge, which is part of every electricity customers' bills. DUoS charges are regulated by Ofgem. Connecting new developments generally involves: • Non-contestable work (reinforcement to existing electricity network) which must be completed by the DNO. • Contestable work (new equipment) which can be installed by a DNO or an ICP (see below). DNOs have a licence obligation to respond to connection requests with quotes which represent the least cost option overall [6] [7]. Requests may be for both contestable and non-contestable work, or a point of connection request for the non-contestable work only.
Independent Distribution Network Operators (IDNOs)	An IDNO owns and operates an electricity distribution network, typically serving new developments within DNO geographic regions and connected to the DNO network. IDNOs differ from DNOs in that they are not geographically based; they own and operate smaller networks within the areas covered by DNOs. They are licenced under Ofgem, although there are some differences in the terms of their licence. There are several IDNOs in operation in Scotland, including Last Mile and GTC who were included in the stakeholder engagement work package of this project.	IDNOs are funded through DUoS charges collected through customer bills. Many IDNOs also manage other local utility networks and infrastructure within their sites (e.g. gas, communications or wastewater) as a complete offering to a development. IDNOs typically adopt electricity networks built by an ICP (see below). Some IDNOs have inhouse or partner ICPs and may be involved with a developer to establish new infrastructure on site. In order to secure the adoption of a local network, an IDNO will offer an 'asset value' payment, which is payable to the developer.

Role	Description	Business driver
Independent Connection Provider (ICP)	The role of the ICP was created to encourage competition within the connections process. An ICP can provide design and installation of new infrastructure for developments. ICPs may have inhouse or partnered IDNOs that they generally choose to adopt their infrastructure, and the ICP and IDNO functions can be coordinated. DNOs can provide a list of ICPs that are active in their area. Energetics is an ICP who were part of the stakeholder engagement work package of this project.	ICPs are contracted and funded by the developer to design and install the equipment. ICPs cannot alter existing DNO networks, but generally interface with the DNO to establish the connection and any reinforcement work needed. ICPs cannot operate networks; an adoption agreement must be set up with an adopting network operator (either a DNO or an IDNO). The installed equipment must comply with the requirements of the adopting network operator, and inspections may be required.

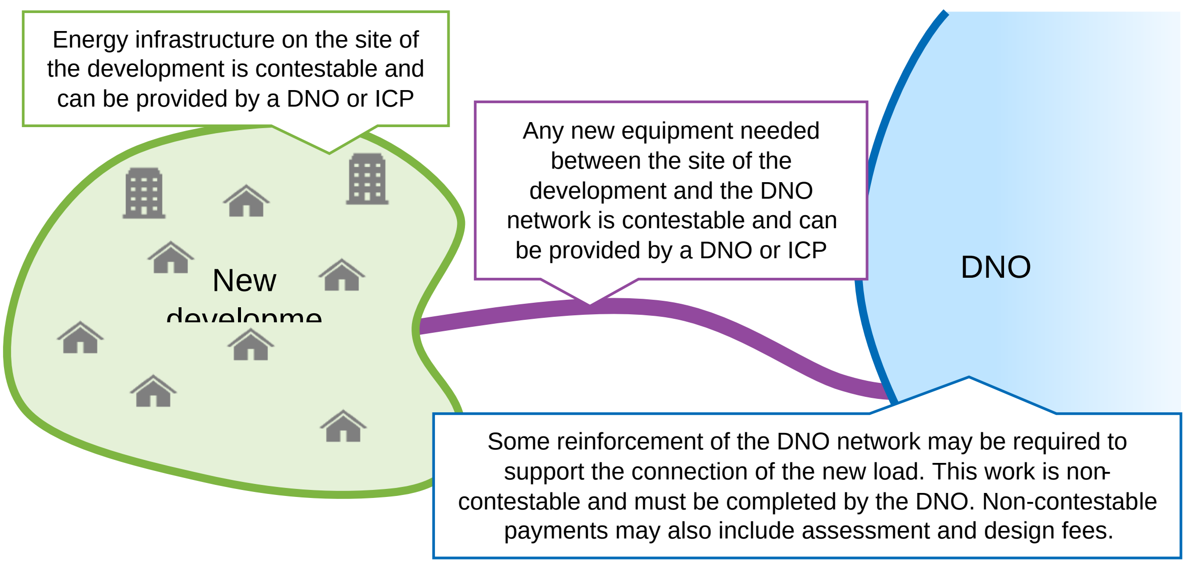
An important distinction in the development of electricity infrastructure for a new development is between contestable and non-contestable work.

The definition of each is as follows:

- **Non-Contestable work:** This is work that the DNO must complete, and therefore cannot be competitively contested. It includes any work on the existing network equipment which is owned by the DNO.
- **Contestable work:** This is work that is not part of the DNOs network, for example, new cables and substation on a development site. Contestable work can be undertaken by DNOs or ICPs, allowing developers to achieve lowest cost through a competitive tender process.

Figure 3-1 below illustrates the differences between contestable and non-contestable work for a new domestic development [6] [7].

Figure 3-1 Contestable and non-contestable work for a new domestic development



This report is focused on the development of electricity infrastructure, as the energy source for zero emissions heating technologies. However, it also considers the process for gas infrastructure as the counter-factual heating technology example.

The process and roles involved in installing gas infrastructure is similar to that for electricity; the Gas Distribution Networks (GDNs) own and operate gas networks in specific geographic regions in GB (the GDN for Scotland is Scottish Gas Network, SGN), and Independent Gas Transporters (IGTs) operate local gas networks within the GDNs' networks, usually associated with new developments. New gas network can be installed by the GDN, or by an independent company who then interfaces to the GDN to connect to their network.

3.2 Connection process

There are multiple routes by which energy infrastructure is established for a new development. This is determined by who with and when the developer forms an agreement.

The process involves four main stages:

- **Establishing the project:** This includes identifying the land and shaping the development, including location and design of homes. This stage is not part of developing the energy infrastructure directly but is vital to understanding the requirements of the infrastructure design. This stage is likely to include selection of the heating technologies and determining other related aspects such as energy efficiency of the buildings and the inclusion of EV charging infrastructure and solar panels. However, the design of the development can evolve over time, in parallel to the stages below. Large developments are often designed, consented and built out in phases, meaning the design of later stages may not be known when building the early ones. The process from buying and identifying land through to building can last many years.
- **Design and agreement:** This stage covers the design of the energy infrastructure to meet the requirements of the development. The parties involved at this stage vary, including:
    - **Developer and DNO:** Where the developer directly engages the DNO to supply the energy infrastructure and the connection, the DNO will produce a design and quote for the new energy infrastructure. This will include any changes and reinforcement needed to their network including the contestable and non-contestable works. If the developer accepts this quote, a formal agreement is set up.
    - **Developer, IDNO, ICP and DNO:** The developer may engage an IDNO and/or an ICP through existing partnerships or through open tender arrangements. Whilst an IDNO and an ICP can form part of an organisational group and offer a coordinated service, the two roles are technically separate. The ICP works with the developer to design the new infrastructure and contacts the DNO to request a quote for the required upgrades to the DNO network for the connection. The ICP

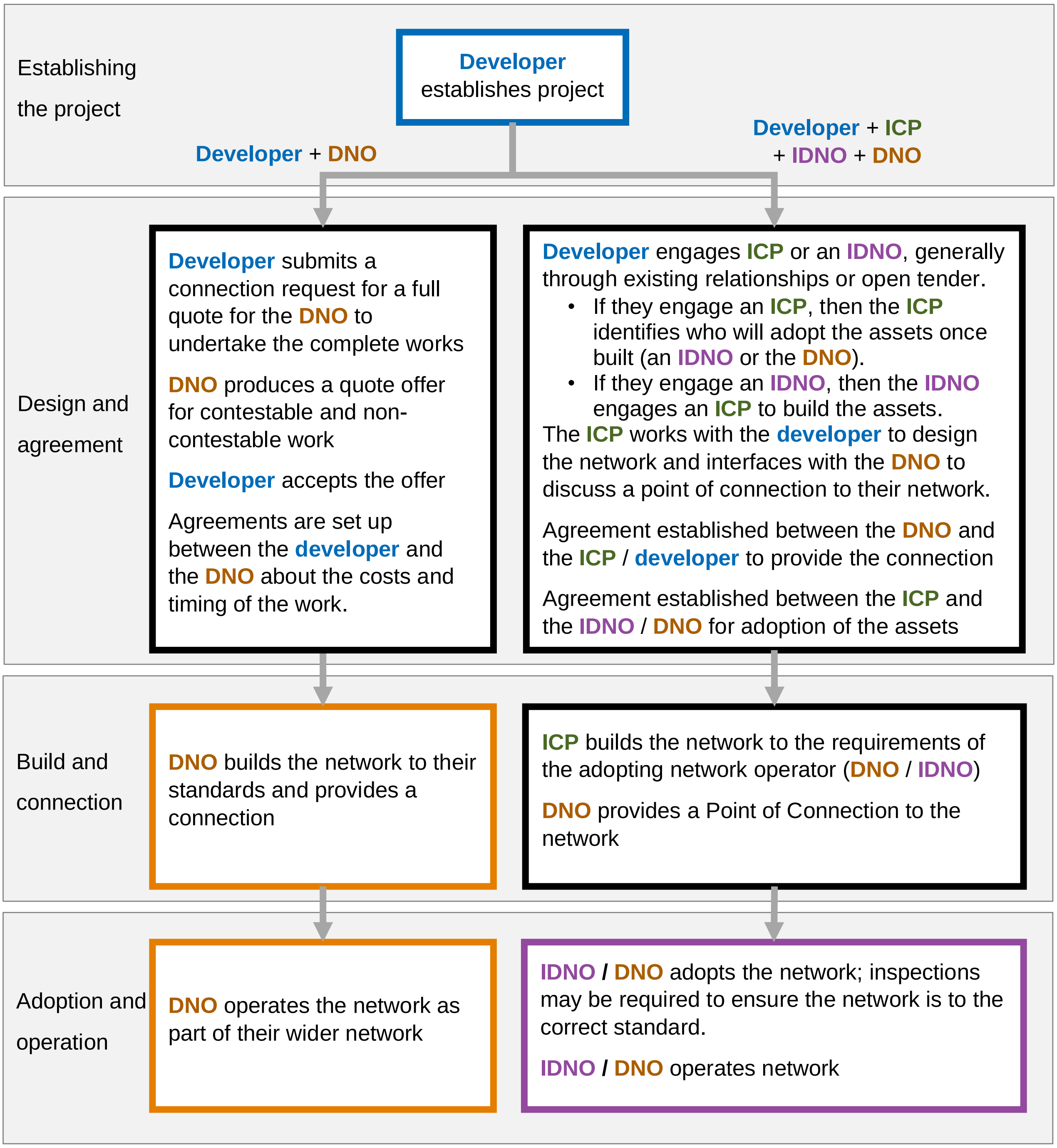
also selects a network operator, which could be an IDNO or the DNO, to adopt the assets after construction. Agreements are set up between the developer, the ICP, the DNO for connection, and the IDNO / DNO for adoption of the assets.

  - In all cases, there may be further agreements and contracts required with landowners and other parties to support the infrastructure development and routing of the network from the development site to the connection point on the DNO network.

- **Build and connection:** The new energy infrastructure on the development site and any routing between the site and the connection point, is constructed by the DNO or ICP. The DNO also carries out network changes or reinforcement to support the connection of the new load. An ICP must build the assets to the requirements and standards laid out by the network operator who will be adopting the assets, who may also wish to sign off designs and inspect installations. Some ICPs are authorised to undertake work on the DNOs network, meaning that there could be very little input from the DNO unless reinforcement is required. If the infrastructure was built by an ICP, the connection may need to be inspected and information shared so that the IDNO / DNO is confident that the new network connection will not cause issues on the existing network. Where there is an existing relationship and track record between the ICP and the IDNO or DNO, then this process may be shortened.
- **Adoption and operation:** Operation of the network includes maintaining the equipment and responding to faults and supporting future developments on the networks (e.g. connections of new load). The new network can be operated in two main ways; if the DNO built the network or if they adopt it from the ICP, it is operated as part of their wider DNO network. If an IDNO adopts the network, they can operate it going forward as a smaller, local network connected within the DNO network. In some cases, high voltage assets built by the ICP may be adopted by the DNO, and an IDNO adopts only the low voltage network. Ongoing operation and maintenance costs are recovered through Distribution Use of System (DUoS) tariffs.

The process is described by a process flow diagram in Figure 3-2.

Figure 3-2 Process for establishing electricity network infrastructure for new housing developments



3.3 Key drivers for decision making

There are several key decision points during the process to establish electricity network infrastructure for new housing developments. The most relevant for this project include:

- **Selection of heating technology**
- **Choice of building fabric and other technologies**
- **Choice of parties to engage in the design and build**
- **Design of the energy infrastructure**

Details in respect of the decision makers and main factors that drive these decisions are provided in the sections below:

3.3.1 Selection of heating technology

There are many different heating technologies and suppliers available for installing into homes. These are described in Appendix A3 and summarised below:

- **Conventional gas boilers:** Gas boilers are the baseline of this study; conventional gas boilers incur a connection cost for developers who are connecting properties to the gas grid. They do not draw any significant load from the electricity grid.
- **Resistance heating:** Resistance heaters create heat by running an electric current through a resistor, and generally operate as stand-alone convection or storage heaters. Resistance heating systems have low capital costs due to their cheap parts and simple installation, without the need for property wide wet central heating systems. However, the operating costs are relatively high compared to other options due to the electricity to heat conversion rate.
- **Heat pumps feeding individual properties:** Heat pumps include air source heat pumps and hybrid heat pumps (which uses a gas boiler to support an air source heat pump). Other heat pump options, such as ground and water source heat pumps, are less common for an individual domestic property scale due to the high installation costs and access to land/water requirements. The operational costs of a heat pump are generally modest, as the efficiency can be very high (where a unit of electricity input can result in 2.5 to 4.5 units of heat output).
- **District heating and shared heating systems:** District and shared heating systems provide heat to multiple properties through a pipe network. This solution has the largest infrastructure costs of the options discussed here but has the potential to have the highest efficiency. Their scale and dedicated housing mean that they do not take up space in end-users' homes. They can be configured to store heat in advance of demand and can be optimised to provide the required heating load with minimal impact on the wider energy systems. The heat network can be fed by electrical means (for example through ground or water source heat pumps), with boilers burning gas, biogas or biomass, or with waste heat from industry or other activities.
- **Emerging heating technologies:** Innovative technologies are entering the low carbon heating market as new potential solutions for developers. Whilst

they are worth noting, they have not become the focus of this report due to their commercial immaturity. Technologies reviewed include phase change materials, heat recovery ventilation, transcritical heat pumps and infrared heaters.

The choice of heating technology is driven by the developers. The stakeholder engagement activities identified that most developers install individual gas boilers as the preferred heating technology. Where there is not a gas network available, which is generally the case for more rural and remote locations, electric heating is installed, which is most likely resistive heaters or air source heat pumps. Some regions are now used to heat pumps, and they have become a proven default thus future-proofing their housing stock going forward.

The main drivers in this decision are:

- **Meeting building regulations and requirements:** building regulations include requirements to meet sustainability standards, which may be met through the selection of more sustainable options. However, there are also other technology and building fabric aspects that might be used to meet the requirements. Some developers may choose to exceed the minimum requirements, reaching Bronze, Bronze Active, Silver, Silver Active or Gold level. This will increase costs, but may be considered a selling point, or may be driven by local efficiency targets.
- **Cost to install the technology:** Developers are driven by cost in many of the decisions they make, which includes the selection of heating technology. Access to low cost technology may be influenced by existing supplier relationships. This is particularly the case for larger developers, who may have agreements with suppliers to provide appliances in bulk at reduced costs or increased convenience.
- **Understanding and experience of the technology:** A developer is more likely to select a technology that they have experience in, and that they fully understand. It is also attractive to use technologies that technicians have skills and experience in installing and maintaining.
- **Cost:** Some developers prioritise the cost to operate. This is a particular focus for housing associations building affordable housing, but private developers are also concerned with developing desirable homes for their customers.
- **Ease of operation and maintenance:** The usability and interface of the technology will impact the desirability of the property. The ease of use may also impact the effectiveness and cost of the technology, as if the heating system is easy to use and understand it is more likely to be properly managed.

It is widely recognised that the selection of heating technologies must change going forward, to include decarbonised and zero emission heating systems. Some developers may increasingly select zero emissions heating options without the mandate of regulation, for example if they have specific corporate targets or they see the demand in their target customer base. However, the stakeholders generally agreed that decarbonised and zero emission heating for most new developments would need to be driven by regulation.

Decarbonised and zero emissions heating options that are considered more likely to be adopted in the short term include heat pumps or other forms of efficient electric heating. The main barriers for adoption of these technologies, cited as reasons that they are not being adopted now, include a lack of understanding of the technology and concerns about cost to install, operate and maintain. The understanding and experience of future occupiers of the homes must also be considered; there is a concern that the alternative heating technologies may be considered undesirable, or that occupiers will not understand how to operate them effectively and efficiently, potentially increasing operating costs or reducing their lifespan.

District or shared heating systems can provide zero emissions heating, if fed by technologies such as ground or water source heat pumps. This technology may be more efficient than individual home heating options and can be managed centrally to maximise efficiency and flexibility over the development as a whole. However, there are significant barriers to adoption; stakeholders referred to homebuyers and occupiers wanting choice of supplier and the freedom to make changes to individual homes, while a district or shared heating system locks the home into a single supplier of heat. This perception may be less dominant for tenants renting properties, including privately rented and affordable housing, which can be managed through a landlord.

3.3.2 Choice of building fabric and other technologies

The choice of heating technology for a home cannot be considered in isolation. The wider building and development design has a significant impact on the energy infrastructure, for example, how insulated the buildings are and if EV charging or solar panels are installed.

The fabric of the building, including the level of wall, roof and floor insulation, thermal efficiency of the windows, and effective draft proofing, will impact the heating requirement of the building. This may mean a difference in the appropriate size and design of the heating technology.

EV charging is a significant energy load for a domestic property, potentially having as much impact on the electricity infrastructure requirements as moving from gas to electric heating. Other appliance choices, such as the cooking source or the existence of power showers will also impact the energy requirements. Note that the installation of gas cooking appliances was cited as becoming less common, or even obsolete.

The inclusion of solar panels on new developments can impact on the requirements of the electricity infrastructure in unpredictable ways, particularly the connection request to the DNO. Solar panels, as a generation technology, have the potential to export electricity to the wider electricity network, and this results in additional technical requirements on the network equipment. The connection request for a development must include details of the generation technologies to be installed, and this may significantly increase the connection cost depending on the status of the local network.

These technology choices are generally made by the developer, driven by the energy efficiency requirements of the building regulations and any local planning stipulations. The Standard Assessment Procedure (SAP) is the methodology used across the industry to ensure homes that are being built meet energy and environmental performance requirements [3]. There are many ways in which a developer may choose to meet the requirements, and the SAP methodology sets out how different energy efficiency measures can be compared and combined; a developer may choose to meet the requirements by selecting a lower carbon heating technology, such as a heat pump, or may instead choose to more effectively insulate the property or install solar panels. The SAP methodology does not necessarily reflect the ways in which these choices interact, which is an aspect that should be taken into account to ensure a well-designed heating solution.

3.3.3 Choice of parties to engage in the design and build

As illustrated in Figure 3-2, the set of stakeholders involved in establishing electricity infrastructure can vary from development to development. Developers have the choice to engage a DNO directly, or to contract the design and build of the energy infrastructure to an ICP. Where an ICP is driving the design and build, there is also a choice about which network operator will adopt the equipment.

The factors for these decisions are summarised in the bullets below:

- **Size of development:** Generally, developers of single home and very small developments are likely to engage the DNO directly, or where an ICP provides the new network equipment, this is adopted by the DNO. Larger developments are more likely to have more complex arrangements including ICPs and IDNOs.
- **Competition in connections provider:** The developer has the opportunity to seek the most cost-effective option for providing connections for the properties on the development. They may issue a tender, receiving submissions from multiple ICPs and comparing this with a quote provided by the DNO. The selection of the provider is generally driven by cost, though developers may have existing relationships with an ICP or IDNO, which may provide them confidence in the service and convenience.
- **Competition in adopting network operator:** Where the energy infrastructure is being installed by an ICP, a network operator needs to be identified to adopt and operate the network. It is common for IDNOs to offer an ‘asset value’ payment, which is payable to the developer. This value is determined through an individual assessment by each IDNO which balances the desirability of gaining the contract with the potential profits that can be gained through DUoS charges over the operating costs of the network over time. DNOs do not offer asset values to adopt the infrastructure, and the asset values offered by the IDNOs is often the deciding factor for the selection of the adopting network operator. Therefore, it is most common for energy infrastructure on developments to be adopted by IDNOs. Note that this can happen at any stage of the connection process but it is likely to happen at the tender stage with the developer to ensure the ICP can provide a true reflection of the cost of the infrastructure works, and increase their chances of winning the work.

3.3.4 Design of the energy infrastructure

The design of the energy infrastructure, including the onsite infrastructure, the connection route and any DNO network reinforcement, is carried out by the developer or the ICP, driven by the energy requirement of the development. Electricity networks are designed to supply the peak electricity demand expected from the loads connected to it at any one time.

The maximum expected demand across a housing development is calculated through taking into account 'diversity'; the assumption that customers will use their loads at different times throughout the day, and therefore the maximum demand experienced on the network is significantly less than a simple addition of all connected loads. The After Diversity Maximum Demand (ADMD) is calculated either by:

- **The DNO:** Where the DNO is providing the complete network installation, including contestable and non-contestable work, they will calculate the ADMD of the development based on the data provided in the connection request.
- **The ICP:** Where an ICP is managing the connection, they will calculate the ADMD of the development based on the design of the development, meeting the requirements of the adopting network operator. They design the network to meet these requirements and inform the DNO of the size of the required connection so that they can design the non-contestable part of the work.
- **The developer:** The developer may see it necessary to identify the ADMD of the development themselves in order to inform the tender process, or to ensure a full understanding of the connected technologies.

The specifics of how the ADMD of the development is calculated differs between different stakeholders, meaning that the same development with identical designs may be result in different maximum demand calculations. The calculations have been built up over time, taking into account significant data and experience about the behaviour of electrical load over time. However, the impact that low carbon technologies (e.g. zero emissions heating and EVs) have on this behaviour, and the appropriate diversity assumption for them, is not yet well understood. This results in assumptions that are often conservative and inconsistent between stakeholders.

There is work being undertaken by some stakeholders to build greater understanding of low carbon loads and therefore enable more informed and efficient network design, and to develop a consistent approach to calculating ADMD across multiple stakeholders. An example of this is work being undertaken by SPEN and SSEN who are developing ADMD calculators that take more detailed data into account.

4 Costs of new energy infrastructure

This section discusses the costs of establishing energy infrastructure for new housing developments and the impact of zero emissions heating. This includes findings from stakeholder engagement, literature review and the modelled case studies.

4.1 Allocation of costs

Costs for new energy infrastructure is allocated across different organisations as part of the connection process, with each organisation recovering their investments at a later stage.

4.1.1 Allocation of costs to housing developers

A developer will pay the infrastructure costs for a new build, and potentially any reinforcement costs to provide the capacity required to meet the developer's energy demands on site.

The costs allocated to a developer depend on the type of work being done:

- **Assets installed for the sole use of the development:** A developer will pay the full costs of any contestable work (any new assets that are installed) that are installed for the sole use of the development [6] [7]. This can be a judgement on the part of the DNO; where the asset being installed releases additional capacity and there is likely to be an additional connection in the area, then the costs may be able to be shared. Alternatively, even if an asset releases additional capacity and is not being taken by the development, if it is located in an area of low development the costs may be allocated entirely to the developer. This is payable to the DNO or ICP installing the assets. This does not include any reinforcement work higher up in the network.
- **Reinforcement of network at or directly above the connection voltage level:** For the connection voltage level or the next higher voltage level a developer will pay a proportion of any reinforcement costs needed to provide additional capacity to accommodate the development site (assuming that the released capacity is not solely taken up by the new development) [6] [7]. Assets are installed at set ratings which can be larger than the individual development requirement. Reinforcement costs can be expensive and prohibitive for a new development, and there are rules in place with the network operators to calculate how much proportion of the total cost the developer will pay. This apportioned cost is calculated based on the capacity the developer has requested, and what new network capacity the DNO provides. Any payments for reinforcement work owed by the developer are payable to the DNO directly or through the IDNO or ICP if they are managing the connection.
- **Reinforcement at more than one level above the connection voltage:** The developer will not pay reinforcement costs associated with network reinforcement beyond the voltage above the connection voltage level [6] [7].

The developer may receive an asset value payment from the adopting IDNO to help offset the cost of energy assets. This asset value varies from site to site based on the IDNO's view of the potential revenues from operating the network and the perception of the competition to win the right to adopt it. Stakeholders cited cases where no asset value was offered at all, right through to a value greater than the asset installation and connection costs.

Going forward, the developer will recover their investment in the development as a whole by selling the homes or retaining the properties as a rental asset. While the intention will be to recover costs and make a profit, the sales and rental prices that can be achieved will be driven by the wider property and rental markets, meaning that it is not generally the case that increases in costs are 'passed on' to eventual occupiers. Instead, an increase in costs at a particular development generally results in a reduction of profits for the developer.

4.1.2 Allocation of costs to ICPs

Where the contestable work is being provided by an ICP, the developer will pay for the work they undertake. The ICP is also likely to be the interface to the DNO when dealing with the connection costs, and any asset value payment from an IDNO. These asset payments and costs may be combined together in a single offering to the developer at the beginning of the project or in response to a tender.

The ICP may take on a proportion of the risk of the works, including any unexpected changes and cost increases in the work the ICP is undertaking, or the reinforcement works carried out by the DNO. This will be defined in their contract with the developer.

4.1.3 Allocation of costs to IDNOs

An IDNO will pay an asset value to adopt assets as part of their network onsite. As mentioned above, an IDNO will offer an asset value based on the predicted income they will receive for operating the assets going forward.

The asset value payment and subsequent operation and maintenance costs are recovered through DUoS charges payable by every connected electricity customer as a small proportion of their bills. There are regulations governing the amount that can be recovered through DUoS, as an individual customer does not have the choice to select their network operator. Therefore, DUoS is regarded as relatively fixed, and any variation in costs must be absorbed by the IDNO.

4.1.4 Allocation of costs to DNOs

Depending on what has been requested, the DNO quote will include only the non-contestable works (a 'point of connection' application), or both the contestable and non-contestable works (a full application).

When a connection request is made to the DNO directly by the developer, there are two types of schemes considered in the design stage of the network. These are listed below [6] [7].

- **Minimum Scheme:** This is the connection design solution with the lowest overall capital cost, which provides the required capacity for the site. This represents the minimum amount of work that is required to establish a connection cost to the developer.

- **Enhanced Scheme:** In certain circumstances the network operator may design an Enhanced Scheme, which includes additional assets or larger assets beyond those required to simply supply the new connection. This might be to serve future expected loads, or to release capacity for network security or efficiency reason. This decision can be driven by the DNO or the developer.

The apportioning of costs by the DNO is as follows:

- **Assets installed for the sole use of the development:** As discussed above, the assets installed for the sole use of the development are paid for by the developer (potentially through an ICP or IDNO).
- **Apportioned reinforcement costs:** Reinforcement costs will be apportioned to the developer based on the portion of released capacity the individual development requires. The remaining costs are 'socialised' (recovered through DUoS of every connected customer to that DNO network).
- **Reinforcement costs covered by the DNO:** If reinforcement is needed higher up in the network stream, the DNO will pay the full reinforcement costs and recover this through DUoS.

4.1.5 Ofgem Significant Code Reviews

The Targeted Charging Review (TCR): Significant Code Review (SCR) was launched by Ofgem to determine how network charges should be set and recovered. [22].Ofgem had concerns that the current framework network operators use to recover their investment may result in inefficient use of the networks and unfair outcomes for consumers. The review was set up to respond to increased adoption of generation technologies such as solar panels by businesses and homeowners, who are still relying on the grid for part of their supply. The review was launched in August 2017 and Ofgem published their decision in December 2019.

One of the areas affected by the changes are residual charges. These are charges designed to recover sufficient network costs such that that network companies can recover their allowed revenue as defined under Ofgem's price control. Residual charges, which can vary between DNOs, make up around 50% of DUoS charges and around 10-15% of electricity bills, and are currently based on energy consumption from the network.

Under the current arrangement, customers who have onsite generation can reduce their demand from the network, thereby reducing or even avoiding payment of residual charges. Ofgem's decision is that distribution residual charges will change from one based on energy demand to a fixed charge on all households and businesses. The charges will be applied to final demand users (i.e. not including generation-only or storage-only connections). These fixed charges will be applied in bands, according to agreed capacity or energy demand and voltage level.

The TCR is complete, and the above changes (and other changes from it) will come into effect from 2022 onwards.

A second review is underway; the Electricity Network Access and Forward-Looking Charges SCR [23]. One aspect under consideration is the connection charging boundary definition; this describes the elements of any reinforcement work that may be apportioned to the connecting customer. The review is considering narrowing this boundary, for example, so that connecting customers contribute only to reinforcement at the connecting voltage level (currently this is the connecting voltage level and one voltage level above, plus any transmission reinforcement). This may considerably reduce the costs that some developer might pay to connect to the DNO network and will reduce some uncertainty in the connection costs. The review was launched in December 2018 and is currently ongoing.

4.2 Estimating costs associated with new energy infrastructure

The network infrastructure and connection costs can be broken down into three main categories.

- **Network reinforcement:** The costs of connecting additional load onto the existing network will vary between sites and is dependent on the size of the load to be connected (i.e. the size of the development and selection of technologies), the available capacity of the local network to support additional load, and the work needed to release additional capacity if required. While the size of the additional load is based on site design within the control of the developer, the available local capacity and required work can vary greatly between locations. A site that has spare capacity to accommodate a new development will incur less costs than for a network where network upgrades are required. Reinforcement costs can vary from very low to millions of pounds, even for a given development size, and therefore the likely required reinforcement costs are an important consideration when considering the location and design of a development.
- **Network connection route:** The connection route between the infrastructure on the site of the development and the point of connection to the existing DNO network can vary in distance, complexity and cost between sites. The costs of routes are driven by the length of connection, and topology of the route, for example the need to cross waterways or roads. The need to cross privately owned land can also add cost and complexity with the need to organise access and wayleaves. Where the route is long and complex, this can make up a significant proportion of the infrastructure costs. Note that the scale of additional demand will rarely impact these costs significantly, unless they impact the required network connection point.
- **Energy infrastructure onsite:** The costs of building the energy infrastructure onsite to serve the development are more predictable as they are less likely to be affected by factors beyond the control of the developer. These costs are more directly driven by the requirements and design of the development itself.

When considering requesting capacity from the DNO, there a number of tools available on the DNOs website which gives an indication of how much spare capacity could be available to accommodate the capacity requested, or whether the network is heavily constrained.

Examples of these are heat maps, which show the DNO network layout and indicate areas that can more readily facilitate new connections [24] [25]. The electrical infrastructure in any region is provided in the Long-Term Development Statement (LTDS). The LTDS gives an estimate of the demand on the network at each location, the generation capacity, and forecasted spare capacity in the next five years [26] [27]. For each network licence area, the local DNO maintains, updates and publishes a new LTDS every year. Note that both the heat maps and LTDS only provide an indication of how much capacity could be available. A full assessment is performed when a DNO receives a connection request which may produce results that are not reflected in these tools.

Each DNO in GB under the terms of their licence condition are required to maintain and publish a connection charging methodology document. This gives an indication of the range of costs that are likely to be incurred when installing electrical assets as part of the connection offer. This includes individual item costs for substations and cable routes, as well as the assessment and design charges for different complexities of connection request. The site-specific nature of much of the work means there is significant uncertainty associated with these costs, hence they are represented in the connection charging methodology by wide ranges [6] [7].

4.2.1 Range of costs associated with case studies

The technical modelling work package of this project considered a set of case studies in order to explore the range of costs associated with the installation of energy infrastructure for new developments. Refer to Appendix A2 for more information on the definition, assumptions and approach for the modelled case studies.

The modelled case studies are described in Table 4-1. The table also shows the modelled electricity infrastructure and connection costs for the base case assumption of gas heating.

Table 4-1: Modelled case study descriptions and results for gas heating assumptions

Case study description	Assumed required infrastructure See Appendix A2 for more detail	Modelled energy network connection costs
Private housing development 300 homes made up of a mixture of 3, 4 and 5-bedroom homes, and 20% affordable homes, in the North Glasgow area. This is a suburban location, with a strong local electrical network.	Onsite equipment includes one substation and service connections to each property. The connection route is assumed to be 30m.	Electricity: £262k to £586k Gas: £90k to £150k
Social housing development 60 homes made up of 30 semi-detached houses (3, 4 and 5-bedroom), and 30 flats (1 and 2 bedrooms, 3-storey), in the Dunfermline area. The electrical network in this area is highly	Development is connected via the low voltage network, requiring no additional substations. A 100m connection route is assumed.	Electricity: £49k to £105k Gas: £54k to £72k

constrained, with very little remaining capacity before significant network upgrades are required		
Small scale rural development Small development of 10 detached homes in a remote rural area. The modelled network capacity is based on a substation near the Scottish border with England.	Development is connected via a new pole mounted transformer. The connection route is 200m long.	Electricity: £40k to £86k Gas: £9k to £12k

The real development case studies that were provided by stakeholders were compared to the examples above to validate the model.

There are several notable costs that are not included in the scope of this project, such as the costs of the heating technology appliance, installation costs and the operational costs of the resulting heating system. These costs are important to consider when comparing costs of heating technologies and are included in the scope of a separate project commissioned by the Scottish Government; Costs of Zero Carbon Heat Research carried out by Ramboll.

Any costs to divert existing network routes on the site of the development can be significant, but as they are not impacted by the choice of heating technology they have not been considered here.

4.2.2 Impact of zero emissions heating technologies

Each of the modelled case studies were assessed to estimate the impact of heating technology choice on the energy asset costs. The technologies included in the assessment are shown in Table 4-2.

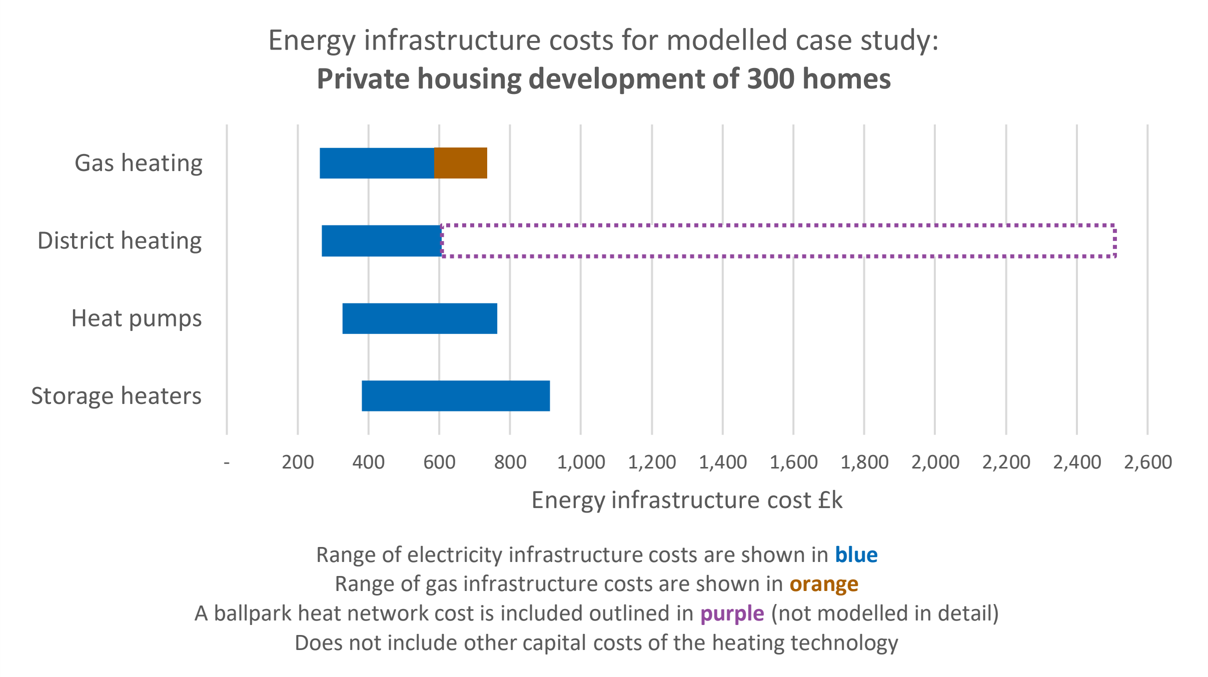
Table 4-2 Modelled case study heating technology definitions

Technology	Assumption
Storage heaters	Assumes storage heating systems are installed in each home with an electrical emersion heater to provide hot water. It is assumed that the storage heating and emersion heaters are managed to minimise their contribution to the peak demand on the electricity network.
Heat pumps	Assumes that an air source heat pump is installed in each home with an electrical emersion heater to provide hot water. It is assumed that the heat pump and emersion heater is managed to minimise their contribution to the peak demand on the electricity network.
District heating	Assumes that a district heating system will provide space and water heating across the development. This is fed by bore hole ground source heat pumps and a thermal store.

4.2.2.1 Private housing development

The modelling of the private housing development of 300 homes found that the infrastructure costs varied moderately with the change in heating technology. This is illustrated in Figure 4-1 below.

Figure 4-1 Range of costs for different heating technology options for a larger private development site. Costs include installation of energy infrastructure.



The conclusions from Figure 4-1 are as follows below:

- **District heating:** District heating can be shared across the whole development and optimised to minimise its impact on the electricity network, by minimising the impact on the peak demand of the site. For this reason, the modelled electricity network connection size increased by only a small margin compared to the gas case, and no additional electrical infrastructure was required. The electricity infrastructure costs for the district heating case on is £269k to £607k, which very similar to the electricity connection costs for a development that only includes gas heating. However it is noted that district heating systems have the most significant installation costs of the technologies modelled; whilst a detailed review of these costs is outside the scope of this project, to enable a fairer comparison, Figure 4-1 provides an indication of the installation costs of a district heat network.
- **Heat pumps:** The modelled electricity network connection size for a site with heat pumps is markedly higher than for gas heating, and as a result, additional infrastructure is needed at site to accommodate the increase in capacity. This results in an increased electricity network cost compared to gas and district heating systems, with total costs ranging from £326k to £763k.
- **Storage heaters**: Storage heaters have the biggest impact on the electricity connection size out of all of the modelled heating technologies. This is because storage heaters are less efficient that heat pumps and will require a

bigger connection to the site. As a result, there is a substantial increase in costs, with the total ranging from £381k to £913k.

4.2.2.2 Social housing development

The location of the social housing development is based on an area that is heavily constrained, and where the release of additional electrical network capacity is costly. This means that while the costs related to the electricity infrastructure when gas heating is assumed are moderate, any of the electricity heating options require reinforcement of between £4.2m and £6.5m. While this might seem like an unusual case, the stakeholder engagement revealed two real case studies in very similar circumstances (see Appendix A2.3 for more information):

- **Dunfermline case study:** Dunfermline is a high development area, with frequent additional developments being built and connected. This means that the area has developed to the limits of the local network. Recently a development of 63 homes was sized carefully to use up the last of the existing capacity in order to be approved for connection. Any additional developments will require reinforcements costing approximately £5m. Note – the social housing development network assumptions are based on the Dunfermline network before the latest development was quoted.
- **Maiden Hill case study:** The initial design of this development included only modest low carbon technologies, and the connection request resulted in a modest quote from the DNO. However, when the site was re-designed to include low carbon technologies in 30% of the planned properties, the DNO assessment and design process revealed a new high voltage substation would be required alongside complex high voltage cabling, costing approximately £7.5m.

The reinforcements triggered by exceeding the modest available capacity will release significantly more capacity than is needed by this development. As this is a high development area, the DNO is likely to be able to charge the developer for only the capacity they need, with the rest of the asset value being covered by other developments. A portion of the total asset value will also be socialised through DUoS charges.

This means that from the developer perspective, the cost to establish electricity network connection for the electric heating options is reduced to between £400k and £1m. While this is still a significant cost, it may be the difference between a commercially viable project and a project being abandoned. Note that if the network was not a high development area, with no evidence of significant development in close proximity, then the asset would be classed for the sole use of the development and the developer would be charged the whole cost. This was the case for Maiden Hill, leading to the developers and other stakeholders needing to find alternative solutions. This is detailed further in Appendix A2.

4.2.2.3 Small scale rural development

For the small scale rural development, the selection of heating technology has an impact on the network connection size, however the variation in demand is not enough to result in additional network infrastructure required, and as a result, the electricity infrastructure costs do not change across the heating technologies.

4.2.3 Impact of electric vehicle charging

The impact of adding EV charging to a development will increase the demand at the site, thereby putting more pressure on the network. The technical model includes the option of adding EV charging to every property onsite, both using standard and smart charging.

Smart charging uses optimisation control to manage the charging load away from the time of peak demand, thus minimising the impact on the maximum demand of the development. Some stakeholders assume no additional capacity is required to connect smart charging, relying on the charging management to avoid an impact on peak demand. For this project, we have assumed a reduced impact on maximum demand compared to the standard EV charging.

The impact on electricity infrastructure costs with EV charging and smart EV charging is provided below.

- **Private housing development:** For each of the heating technology option, the impact the inclusion of standard EV charging increases the network infrastructure costs of the site with an average increase of approximately 20%. Smart charging reduces the impact on the peak demand at the site, meaning that in some cases this increased cost can be avoided.
- **Social development:** The inclusion of EV charging alongside gas heating would exceed the existing remaining electrical capacity on the network, resulting in the need for the significant network reinforcement. This means that the only modelled case that avoids this cost is gas heating and no EV charging.
- **Small scale rural development:** Where the heating technology is storage heaters or heat pumps, the addition of EV charging (standard or smart) means that a larger transformer is required, increasing the infrastructure costs. This is also the case for standard EV charging with district heating, although using smart EV charging means that the additional cost is avoided.

5 Innovative projects and approaches

European countries are seen as the world leaders of decarbonised heating solutions. In reality they vary greatly with some countries being almost already fully decarbonised, while others are still relatively early in their journey.

Scandinavian countries have been very successful at decarbonising heat. For Sweden, the share of fossil fuels is now below 5%. This has been achieved by removing oil and other fossil fuels for heating in both detached homes and blocks of flats over the past 50 years. Fossil fuel energy has been replaced by both district heating and electricity through resistive heating and heat pumps, which provide up to 75% of the energy demand for heating in buildings. However, critics state that Sweden’s burning of waste, which is a source of heat for the district heat networks, has been at the expense of opportunities to recycle. There is also a concern that there is not enough focus on building efficiency.

In Eastern European countries like Estonia, the largest share of heating is derived from domestic biomass where it is regionally produced and widely available at a low cost.

Western and Central European countries have had difficulty decarbonising heat as they have grown reliant on gas networks embedded into their infrastructure. Without biomass or heat networks to rely on the challenge of heat decarbonisation will be difficult, it is expected that countries will turn to electricity or hydrogen as a primary solution.

Zero emissions heating technologies have not yet been deployed at the scale required to meet the world’s decarbonisation targets. Deploying them at scale presents new challenges otherwise unseen, including the challenge of network constraints. Innovation projects can provide us with the opportunity to investigate methods of mitigating these challenges.

Innovative projects in the UK and internationally have built experience in the electrification of heat and enhanced understanding about technologies and the effects they may have on the electricity network. A selection of projects is discussed in this section, and each project is described in Appendix A4.

5.1 Identifying and understanding heating solutions

The diversity of housing types, standards of thermal insulation and level of grid connection means that there is no one-size-fits-all solution for heat decarbonisation. Therefore, decarbonising heat needs attention at the local level as well as the national level. The project “Spatial analysis of future electric heat demand” is exploring optimal decarbonisation pathways by creating a geospatial analysis of heat energy demand and providing network impact assessments to identify the least regret network investment options required [11]. It is expected that this could assist in guiding what technology is suitable for individual locations to reduce network investment.

“Heat street” is developing an approach to forecasting energy efficiency measures and low carbon heating solutions. The project plans to use zoning assessments that will help to identify areas that may be particularly well suited to heating electrification so that heat electrification can occur at a faster pace with higher end-user satisfaction [12].

A key barrier to the roll out of decarbonised heating technology is a lack of understanding of the technology and its impact on the network. Electrification of heating using heat pumps was assessed in the “Electrification of Heat Demonstration Projects” that aimed to demonstrate the feasibility of a large-scale roll-out of heat pumps [14]. The projects developed, tested and evaluated innovative products and services that could increase the appeal of heat pumps and demonstrate their technical feasibility. The learning from the project was used to improve awareness across the heating supply chain, raise acceptance and support for the wider deployment of heat pumps in GB. Similarly, the “Flexible Residential Energy Efficiency Demand Optimisation and Management” project investigated the feasibility of hybrid heat pumps on the Western Power Distribution network [15].

There is work being undertaken to build greater understanding of low carbon appliances and technologies and therefore enable more informed, consistent and efficient network design. An example of this is work being undertaken by SPEN and SSEN who are developing ADMD calculators that take more detailed data into account when calculating ADMD for domestic developments including low carbon technologies. These are being shared and published between stakeholders in order to build a consistent approach that is well understood.

The electrification of heating can provide unique circumstances for an electricity network where heating systems will draw an unusually large load when the network is cold starting. In the project “Cold Start”, UKPN are building a simulation model to assess how the energy system responds and inform policy and future studies on providing solutions to ensure the power system remains reliable during such events [16].

The project “Electrical Heat Pathways: Looking Beyond Heat Pumps” sought to influence policymakers to give proper consideration to storage heaters in the discussion on heat decarbonisation and ensure that policy does not inadvertently act as a barrier [19]. The project highlights the possibility of commercial arrangements to reward the provision of flexibility and diversity provided by storage heaters.

5.2 Energy management

Energy management solutions use the inherent flexibility of loads to optimise the time that they are used, potentially providing benefits such as reducing overall peak demand, or moving load to times where the grid carbon intensity or the electricity process is low.

Electrification of heating can be used in locations where renewable energy is being curtailed to provide decarbonised heating and reduce curtailment. The project “4D Heat” looked at matching electric heating flexibility with surplus wind power and assessing the cost benefit whilst considering the implications of network constraints in Skye [17]. Key findings were that utilising surplus electricity meant that some consumers could save as much as 18% on their annual home energy bill and 17% of curtailed wind could be absorbed by electric heating systems.

The Northern Isles New Energy Solutions project in Shetland introduced methods of managing the distribution network more effectively [18]. It included, replacing 1,000 homes with modern smart storage heaters with demand response triggers, connecting a 1MW battery and adding an electric boiler to a district heating system associated with a local wind farm. The project allowed the operators to assess the interactions and provide an added level of control for the benefit of the network.

The Maiden Hill case study (see Appendix A2.3) is another example of an energy management project. Increasing the amount of low carbon technologies to be included on site resulted in the maximum demand of the site exceeding the network available capacity, with the costs to release further capacity quoted at approximately £7.5m. In response, the consortium of developers, the DNO, the IDNO and technology providers are investigating using energy management technologies to manage the load to within the existing site capacity by maximising the use of electricity generated on site with solar panels, and managing flexible loads such as hybrid heat pumps and EV charging infrastructure to avoid drawing power at peak times.

5.3 District heating

In the UK, we have limited experience of modern district heating networks. However, there is more experience in other countries such as Denmark where district heating is part of Copenhagen history. It is one of the world’s largest, oldest and most successful district heating systems [20]. The heat used is primarily from waste heat released by electricity generation power stations that would otherwise be vented into the atmosphere. The utilisation of this heat supplies 97% of the city with clean, reliable and affordable heating. The primary costs for developers connecting new properties is the pipework to the properties, consideration of heat generation is not required.

An example of a district heat network being developed in Scotland is Queens Quay, Clydebank [10]. The district heating network will utilise the steady temperatures of the River Clyde to supply heat to nearby properties and residents. The water source heat pump will be sized to meet the majority of the heat networks demand and uses back-up conventional boilers for the rare times that the water source heat pumps can’t meet the demand. The cost for developers is the heat generation technology and the pipework to the properties but the sizing of the heat pump should keep the overall electricity demand for heating low and with little fluctuation.

ENGIE’s harmony project included ground source heat pumps providing heat to 400 flats in eight blocks across two estates in the London Borough of Enfield [21]. The project uses an individual heat generator approach for district heating. Pumps move water round the pipe network, where the water is not artificially heated but instead remains at ground temperature. A “Kensa shoebox” heat pump in each property extracts heat from the ground temperature water and raises the heat provided to 65ºC so that it can be used for hot water and space heating within the property. The system requires district heating pipework as well as individual heat pump units in each property.

6 Key considerations in relation to the 2024 standards

A number of stakeholders were interviewed as part of the stakeholder engagement work package to explore the processes, decisions and costs that are involved in establishing energy infrastructure and connections for new domestic development, and the impact switching to zero emissions heating has on this process. Key considerations for each stakeholder in relation to the 2024 New Build Heat Standards are provided below. Detailed findings from each stakeholder can be found in Appendix A1.

6.1 Key considerations for developers

The major concern for developers in relation to the 2024 standards is the choice of zero emissions heating technologies that meet the new requirements. Gas heating from individual gas boilers remains the preference due its lower installation cost, significant prior experience and the customer familiarity. Some developers are installing a combination of solar panels plus gas or hybrid heat pumps to improve their environmental performance and to meet building regulations.

It is recognised that in order to meet carbon reduction targets, the developers will need to move towards installing electric heating technologies that generate zero emissions at the point of use. The major barriers to this are a lack of experience and confidence in the technology, capital costs, access to supply chain, operational cost and user experience. These barriers will need to be overcome as adoption of these technologies grows.

While stakeholders confirmed that energy infrastructure costs are only a small part of the overall development costs, and so are rarely a significant decision factor for the selection of land or design of a development, they also identified examples where the local DNO network is highly congested and the costs of required reinforcement works are prohibitively expensive. The move to electric heating technologies will make this more likely and more frequent. Developers could consider innovative approaches, such as demand response, and collaboration with other developers to share or reduce the cost of reinforcement.

There is also a concern around the transition to the new 2024 standards. A single development project might encompass several years from identifying and purchasing land to the development being built. This means that a project that was in design and planning in 2019 might be being built in 2024. Changing the assumptions of these existing projects to meet the requirements of the 2024 standards may undermine the business case of these developments. This may have serious implications for the developers and should be considered while planning the implementation of this standard.

6.2 Key considerations for IDNOs and ICPs

Different low carbon technologies present challenges which need to be considered in order to design and manage the electricity network. Clarity over the technology type and energy consumption at the site is required for the IDNOs and ICPs to design their networks to meet the demand.

The inclusion of electric heating cannot be considered on its own. The inclusion of other technologies such as EVs, solar panels, energy efficient appliances as well as the building fabric will impact the energy consumption of new homes. This need be understood and considered going forward.

There may be increased incentives to include energy management on the local network of a development, in order to avoid expensive infrastructure costs and meet the DNO connection requirements. This needs to be considered by IDNOs, in collaboration with developers, DNOs and technology providers.

One impact of electrical heating technologies is that gas networks may no longer be needed at new developments. The impact of not needing gas is that the work contracted to the ICP is reduced, which would lead to reduced revenue. Similarly, it will reduce the infrastructure that can be adopted by an IDNO, reducing the potential revenue from their involvement in the development. However, if district heating technologies are adopted ICPs and IDNOs may benefit through their development and adoption.

6.3 Key considerations for DNOs

The transition towards the full electrification of heating in new homes will increase domestic electricity demand. Investment in new innovative approaches to address this challenge is needed in order to better understand the impact that low carbon technologies have on peak demands, whilst minimising the costs apportioned to consumers. It is acknowledged that DNOs cannot be a blocker to innovation and the transition towards net zero.

A proportion of the costs associated with the adoption of zero emissions heating will be socialised to electricity customers, with societal and energy system benefits. This needs to be considered carefully to ensure it is fair and valuable for society.

Some DNOs have not been considering the impact that low carbon technologies in the future has on their existing connections, except when they receive applications requesting new capacity. Consideration as we approach the next price control will be to identify strategic investment in areas on the network that are likely to be constrained in the future and replace the assets.

Zero emissions heating systems, like other low carbon technologies, have the potential of impacting power quality. While on an individual level, appliances and technologies should be compliant with power quality requirements, adding high volumes to the network could result in more significant impacts which will require management by the DNO.

6.4 Key considerations for technology manufacturers

Manufacturers of zero emissions heating technology should be aware of the requirements of the New Build Heat Standard, to ensure that their products comply. Developers of innovative heating or energy management technologies should to understand the requirements of the New Build Heat Standard and how their technology might support in meeting and exceeding the requirements, or in reducing energy infrastructure costs.

The design of solutions should consider energy infrastructure requirements, installation and operating costs, ease of maintenance and the required technical skills to install and maintain the equipment. There is a need to develop solutions that are effective and usable, and there may need to be user education to ensure the residents of the home understand how to operate their heating system effectively and efficiently.

There is a need for zero emissions heating technology manufacturers and developers to collaborate with other stakeholders. In order for these technologies to be adopted widely, experience and confidence needs to be built up by the developers around their installation, use and maintenance, and by the network operators around the impact that they have on the wider energy infrastructure. Inclusion of innovations such as energy management is likely to be easier and more effective if it is considered early in a development project, and where there is close collaboration between stakeholders.

6.5 Key considerations for homeowner / occupier

Project stakeholder contributors cited the key considerations for the occupiers of properties with zero emission heating as including ease of use, resulting comfort levels and energy bills.

Occupiers of new build homes after 2024 will be amongst the first in the country to experience zero emissions heating technologies first-hand. The majority of the GB public are most familiar with central heating systems fuelled by gas or other fossil fuels, where the occupier turns the heating system on when they want to be warm. Heat pump heating systems, for example, must be operated in a different way, allowing the system to maintain the temperature on an ongoing basis.

User education and ease of use of new appliances is essential as the industry moves towards zero emissions at the point of use in new homes going forward.

In addition, the operational costs of the system should be considered when installing the heating technology. There is a danger that resistive heating technologies will be selected as a low capital cost option, but the operational costs of this technology are comparatively high. The low energy efficiency also means that the environmental credentials of this technology is worse than other electrical alternatives.

Another consideration may be the desire to have control over the heating supply decisions within the property. This issue was raised by project stakeholders in respect of district heating technologies; developers and IDNOs perceive that potential homeowners would be put off by district heating systems as they would be locked into a supplier, and would not be able to make changes to the heating appliances in the home.

7 Conclusions

This project, The Research into Electricity Network Constraints and the 2024 New Build Heat Standards project has found that the adoption of zero emissions heating in new developments will generally increase the infrastructure costs for many developments, however, the scale of that increase will be variable based on factors including the selection of heating technology, the wider design of the development, the geographical location of the development site, and the available capacity and status of the adjacent electricity network. In some cases, the impact may be minimal, while in others it will mean that the development becomes unviable. Therefore, the major impact of adoption of zero emissions heating will be an increase in uncertainty for housing developers.

It is critical to consider costs beyond the energy infrastructure, such as the costs of the technology appliance, installation costs and the operational costs of the resulting heating system, when comparing costs of heating technologies. These costs are out of the scope of this project but are included in the scope of a separate project commissioned by the Scottish Government; Costs of Zero Carbon Heat Research carried out by Ramboll.

It is also important to consider buildings and developments holistically. The heating technology cannot be thought of in isolation; the building fabric has a huge impact on the heating load and constraints, and understanding the non-heating load of the house, including the presence of EVs is important to understanding the network impact.

Insight can be gained about the available capacity in the surrounding network through information published by DNOs including heat maps which indicate areas that can more readily facilitate new connections, and the Long-Term Development Statement (LTDS). However, it is increasingly important that developers work with IDNOs and DNOs closely from an early stage in complex developments, and that all stakeholders are open to exploring innovative solutions such as energy efficiency and management. If all stakeholders work together on a development, information can be shared and used in design decisions, and ideas around flexibility, optimisation and innovation can be explored.

There are further barriers to adoption of zero emissions heating technology, beyond the increased energy infrastructure costs. These include a lack of understanding about the technology, a lack of skills for design, installation and maintenance, a lack of supply chain relationships for the technologies themselves, and concern about the user acceptance.

The user experience must be a key consideration when designing and selecting heating technologies. Any technology must effectively heat the home providing a good level of comfort and be understandable and easy to use. As the experience of most of the public in Scotland is with fossil fuel central heating systems, user education may be required to ensure an electricity-based system is operated as it should be. Another key consideration should be the operational costs of the solution, to ensure technologies are selected that do not disadvantage the occupiers.

As increasing levels of zero emissions heating technologies are adopted, confidence and experience will increase in their installation, operation and management. It will be important to consider how to best support the transition towards successful adoption.

7.1 Recommendations and next steps

The next steps following this project could include

- **Combine learning from related projects:** The Scottish Government have commissioned several pieces of work to understand the impact and support the implementation of the 2024 New Build Heat Standard. These projects and relevant external research should be combined, compared and synthesised into a clear, overarching picture to inform policy and implementation.
- **Support the transition to zero emissions heating:** There are barriers to the transition to zero emissions heating including lack of understanding and confidence in heating technologies, business risks for the developers and stakeholder involved in projects, and cost and risk implication of the adoption. The Scottish Government could support this transition by consulting on the issues, barriers and solutions towards the adoption of renewable or zero emissions heating in new homes and developing and promoting best practice.
- **Engage stakeholders in collaboration, innovation and best practice:** A key conclusion is that there is a need for developers, network operators and technology providers to work closely together and be open to innovative methods. Promoting and encouraging collaboration and sharing best practice between stakeholders will equip them to successfully transition to zero emissions heating technologies.
- **Further exploration of district heating:** The district heating technology option was found to have the least impact on the electricity asset requirements and is likely to be the most efficient and optimisable solution. While installation costs are high, new developments should have the lowest cost barriers to adoption of district heat. Exploration of these barriers, benefits and best practice for district heating could be considered.
- **Explore barriers and solutions for adoption for retrofit heating:** This project is focused on new build domestic properties for the 2024 new build heat regulations. However, the adoption of decarbonised heat across the retrofit housing stock is a significant challenge, with very different barriers and solutions. The Scottish Government could build knowledge in this area to inform policy and implementation to support this transition.

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Appendices

The appendices are as follows:

A1: Stakeholder engagement findings

A2: Case Study Report

A3: Heating options

A4: Innovative project summaries

A1 Stakeholder engagement findings

This section presents the notes that were gathered from the stakeholders either through an interview or from survey responses, which aimed to help understand the processes, decisions and costs involved in establishing energy infrastructure and connections for new domestic developments, and the impact of switching to low carbon and zero emissions heating technologies. The stakeholder engagement also aimed to collect information and data to inform the technical modelling task.

A1.1 Developers

Two interviews were carried out with developers; with Angus Housing Association and CALA Homes. CALA homes engaged further in the project, providing data and information about real case studies and insight. In addition, a survey was issued to a set of affordable housing developers, and five responses were received.

A1.1.1 Interview: Angus Housing Association

A1.1.1.1 The choice of heating technologies commonly used today

Gas combi boilers are the preferred technology, provided there is direct access to the gas network. Air source heat pumps are chosen for developments that are off the gas grid. This is due to the ease of use for tenants and efficiency. Angus do not install convection heaters, and in the case for retrofit, they would install gas boilers over resistive heaters. Other technologies that are considered are:

- Electric wet heating systems but are expensive to operate.
- Solar heating and wet systems were installed previously but have had issues with complexity.
- Ground source heat pumps are very expensive in capital, so need separate funding.
- District heating systems, which has not been installed to date and is under review.

Decision factors for the choice of heating technology is based on existing relationships with suppliers and cost / ease of use for tenants.

A1.1.1.2 The process for establishing energy infrastructure for new domestic developments

Angus may not be the lead developer within a development but may be part of a larger private development. Section 75 is a planning requirement to provide social housing as part of a private development. In these cases, housing associations may have some influence on the design of heating requirements, but this will be limited.

When they have been involved in decisions regarding energy infrastructure, Angus have preferred suppliers based on their post installation service.

A1.1.1.3 Main drivers for the cost of network connection for developments, and who pays for them

The main drivers for decisions about energy infrastructure is the running costs and ease of use for tenants. To date, gas central heating has been an easy decision, as the capital and running costs are lower.

Costs are recovered through rent, though this is kept as low as possible.

- Rent can be influenced by heating technology, scaled with the aim of keeping overall costs controlled i.e. if a heating technology is considered less efficient, then the rent is lower to compensate.
- However, there is no separate category for heat pumps; they are considered for the purposes of rent as electric heating, with higher operating costs than gas. Therefore, at the moment the rent cannot be increased for a home with a heat pump.
- The Energy Performance Certificate (EPC) rating of a home also has an impact on the rent; the standard rent rate is based on C, D or E ratings. If the house is rated at B or A, then the rent can increase to balance the lower operating costs. If less than E, then the rent is decreased.

The network infrastructure to support Electric Vehicle (EV) charging infrastructure is installed in new build houses and shared parking areas, but the cost of the charging equipment itself is currently too high to be included.

Installing solar panels is becoming common where needed to meet the energy efficiency requirements in the building regulations. There has been a choice between solar panels and ventilation systems, and Angus have found solar panels to be less problematic. The Housing Association want to give the income generated from solar panels to the tenant but have found this to be difficult to arrange. More recent and better technology for capturing readings will make this easier.

A1.1.1.4 Impact of zero emissions heating on connection process

The main impacts of zero emissions heating on connection process are as follows.

- **Infrastructure**: Angus is unsure of the ability of the network to be able to cope with a large increase in demand from heat pumps.
- **Building envelopes:** There is a drive to insulate buildings, and to achieve EPC ratings of B. To date, buildings are generally insulated to meet the building regulations. There might be a drive to go further, but there is also the drive to keep capital costs under control. There is a premium to pay to achieve a higher energy efficiency, but generally funding is insufficient to cover costs. There is the desire amongst developers to go further but quite often the additional costs dissuade housing associations going the extra mile.
- **Tenant behaviour:** Tenants are used to being reactive to heating requirements from being able to get instant bursts of heat from gas boilers. In comparison, heat pumps require proactive behaviour to preheat and maintain the home to a comfortable level, which requires a behavioural change.

A1.1.1.5 Innovative Products

Dundee City Council has engaged in a consultation for funding district heating systems. Angus Housing Association has considered a district heat system for a remote scheme. This only works with external funding and is complex.

Dundee City Council are looking into EV charging points, and Angus Housing Association looked into providing EV charge points in each house for a recent project but found the costs to be prohibitive. The infrastructure will be provided but not the charging points.

Bicycle storage for individual houses will be installed in the Dundee area.

A1.1.2 Interview: CALA Homes

A1.1.2.1 The choice of heating technologies commonly used today

Historically gas heating was the most common choice used by CALA Homes, but they now do a combination of solar panels plus gas and hybrid heat pumps to improve the environmental performance and to meet building regulations. CALA Homes are aware that they will need to move to full electrification of the heat network and are considering options including heat pumps and infrared heat mats.

The decision of the choice of heating is driven by:

- **Meeting building regulations:** Some thought is being considered in exceeding the minimum sustainability standards (Silver / Silver plus). Would like to consider meeting the highest standards but the costs are prohibitive
- **Cost**
- **Practicalities of installing**

Larger developers have more buying power and might be able to get lower cost deals with suppliers, but this is not the case for CALA Homes. CALA Homes is owned by Legal & General, who have made a commitment to reach zero carbon. This has resulted in additional drivers for CALA Homes to invest in low carbon and zero carbon solutions, beyond those mandated by regulations.

A1.1.2.2 The process for establishing energy infrastructure for new domestic developments

Generally, a developer would buy land, undertake initial planning, and pass information to the IDNO, including layout, dwelling arrangement and technologies to be installed. The IDNO would design the network, build and arrange connection.

The rise of low carbon technologies has resulted in a lack of understanding about how to deal with peak load and diversity assumptions, leading to conservative designs and excess costs. CALA Homes have been engaging with the DNOs (SSEN and SPEN in Scotland, and some interaction with English DNOs), and are developing a standardised approach across their areas to calculate appropriate diversity assumptions across developments. They have created a utility sheet for developments, which is then passed on to the IDNOs. This makes it easier for the IDNO to design the network using the assumptions provided by CALA Homes.

A1.1.2.3 Main drivers for the cost of network connection for developments, and who pays for them

Drivers for cost are:

- **Size of connection:** This is driven by the number and type of dwelling and technology selection
- **Location:** The presence of gas and/or local electricity network capacity will impact costs

A1.1.2.4 Impact of zero emissions heating on the connection process

Low carbon technologies have changed the connection process as there is a lack of understanding about how to deal with peak load and diversity assumptions, which leads to network operators taking conservative views on design, which leads to extra costs.

A1.1.2.5 Other points raised

Land is often bought years before homes are built, and large developments are built in phases over many more years. When land is bought, the business case built up around that decision can only be based on the regulations that are in force at the time. This needs to be taken into account when considering the implementation of new rules like the 2024 regulations. If these apply to existing or already planned projects, then it may have serious implications on the developers.

A1.1.2.6 Related projects

CALA Homes is undertaking a related study into the impact of different heating and low carbon technology choices on the energy infrastructure costs, focusing on three case study developments in Scotland.

A1.1.3 Affordable Homes survey response: Hillcrest Homes

A1.1.3.1 When you are developing housing, what heating technologies are generally installed today? What drives this decision?

At present the preference remains gas and more particularly individual gas boilers. If gas is unavailable, then dry electric heating is preferred. This decision is driven by operational cost and maintenance requirements. Gas remains the cheapest option for tenants to run and is easy to operate to control temperature for their living environment. In addition, in-house maintenance teams have the ability to repair and return gas boilers to service or replace electric heaters with minimum delay or impact on the tenant.

A1.1.3.2 Are the costs of energy network infrastructure and connections a significant factor in the design of the development as a whole? Are there any circumstances where they become more significant?

Hillcrest Homes have mixed views on this. They generate a budget for the development through rental income and this is put to the developer / contractor. They have a design brief but are influenced by what can be feasibly provided within the contract. As an organisation they are open to new technologies but only if they can demonstrate value for money to both the tenants and themselves. Circumstances where they become more significant is when gas services are not available, or they are involved as part of a larger development overall and an alternative proposal is put forward by the lead developer.

A1.1.3.3 How will these costs be impacted by the need for low carbon / zero emissions heating technologies such as heat pumps? Are there any wider impacts of switching to these technologies?

The biggest issue with switching to zero emissions and low carbon heating technologies is maintenance, accessibility to and ease of repair. They have looked at and installed several experimental and alternative technologies in the past but unfortunately not to any great success.

They foresee installation costs working within the confines of the development budget as an issue for low carbon / zero emissions heating, as well as availability of installers. In addition, a major factor in the installation of alternative technologies on their organisation was the education of their tenants on how to use them and operate them on a day to day basis. Unfortunately, most people are familiar with gas but not with alternative technologies so the education process can be a timely and expensive exercise.

A1.1.3.4 What data do you calculate or estimate for the design of heating solution for the properties?

Data collection and technical design is predominantly contractor led. Homes will meet the Scottish Governments greener standard and this is verified through average SAP calculations, ratings and average energy consumption savings.

A1.1.4 Affordable Homes survey response: Eildon Housing Association

A1.1.4.1 When you are developing housing, what heating technologies are generally installed today? What drives this decision?

Over recent years Eildon Housing Association’s approach is to use highly efficient gas boilers where mains gas is available and where it is unavailable to provide air-source heat pumps. They find this approach is well suited and a cost-effective way to meet Silver Standards of the SAP Building Regulation requirements; where necessary to meet these standards, they will supplement with solar panels. The second driver is the running cost of the systems which they understand must remain affordable. Third is the technical understanding of the systems both with the property teams and maintenance contractors. The fourth is ease of use and understanding of the systems by their tenants.

Eildon Housing Association are now at a turning point with all current schemes and are assessing what heating systems new programmes will adopt. They have a working principle that air-source heat pumps will be the norm across future programmes.

A1.1.4.2 Are the costs of energy network infrastructure and connections a significant factor in the design of the development as a whole? Are there any circumstances where they become more significant?

Working in a rural part of the country has been a factor in design with many villages in the borders not having access to mains gas. As noted above, ongoing sustainability and a move away from use of fossil fuel will play a more significant factor than energy networks and connections.

A1.1.4.3 How will these costs be impacted by the need for low carbon / zero emissions heating technologies such as heat pumps? Are there any wider impacts of switching to these technologies?

There is an issue around the capital cost of adopting any low carbon / zero emissions heating technology. Eildon Housing Association are assuming heat pumps will increase capital cost at least by £5k per home. Additionally, tenant education requirements and ongoing asset management issues need to be considered. Ongoing asset management isn’t only an issue in respect of ensuring their property team are educated about new systems but also in respect of the availability of maintenance contractors in the borders who are technically qualified to work on new systems.

A1.1.4.4 What data do you calculate or estimate for the design of heating solution the properties?

Currently Eildon Housing Association’s approach is targeted to meet the requirements of Silver Standard, SAP and Building Warrant.

A1.1.5 Affordable Homes survey response: West Lothian Council

A1.1.5.1 When you are developing housing, what heating technologies are generally installed today? What drives this decision?

In the majority of West Lothian Council’s new homes, they install gas central heating. Gas has been regarded as cost effective, easy for the tenant to use and for the council to maintain and meets requirements on sustainability.

A1.1.5.2 Are the costs of energy network infrastructure and connections a significant factor in the design of the development as a whole? Are there any circumstances where they become more significant?

The cost of energy network infrastructure has not generally been a significant factor. At one site however, in Mossend, West Calder, they would have considered air source heat pumps, but this would have required an additional substation.

A1.1.5.3 How will these costs be impacted by the need for low carbon / zero emissions heating technologies such as heat pumps? Are there any wider impacts of switching to these technologies?

One issue that has arisen at a site at Mossend in West Calder is in relation to the capacity of the electricity substation. This is a site for 69 homes, and they may have considered using air-source heat pumps here, but they were advised that there is insufficient capacity at the substation to permit this. It may also impact on electric charging points for cars.

A1.1.5.4 What data do you calculate or estimate for the design of heating solution for the properties?

In most cases West Lothian Council contracts the design and build. They set out what they expect of developers who provide evidence that they have met the requirements. In some case West Lothian Council buys directly from volume house builders, so they have less influence over what is provided. Where appropriate, they would employ building services engineers to calculate the required space heating hot water requirements – all in accordance with the SAP calculations required for Building Warrant.

A1.1.6 Affordable Homes survey response: North Ayrshire Council

A1.1.6.1 When you are developing housing, what heating technologies are generally installed today? What drives this decision?

North Ayrshire Council declared a Climate Emergency in 2019 and is committed to achieving net-zero carbon emissions by 2030. The Council understands that housing has a key role to play in carbon reduction, climate change mitigation, and the alleviation of fuel poverty. The Council's new-build programme aims to support the Environmental Sustainability and Climate Change Strategy by helping to reduce fuel use, and in turn fuel costs and carbon emissions. Consideration as to what heating technologies will be used is on a site by site basis. A number of factors are taken into account, including meeting sustainability requirements, capacity of systems to heat standard house types, and cost.

The Council has just completed two 'sustainable demonstrator homes' within the Dickson Drive development in Irvine. The homes are heated by a 'Sunamp' system supported by solar photovoltaic panels. This project highlights best practice in design and innovation, ensuring benefits from sustainable technologies are maximised. The sustainable benefits from the homes will be evaluated, and the findings shared with partners in order to inform the wider development programme and investment in existing stock. The Council has also installed biomass district heating schemes to service their 123-unit flagship Flatt Road development in Largs, their 49-unit development at Watt Court, Dalry, and their 28-unit sheltered housing facility, Glencairn House in Stevenston. The Council has previously installed air source heat pumps in Cumbrae and a solar assisted heating and hot water system in Saltcoats.

In their experience the cost of installing sustainable heating and hot water systems is significantly more expensive than those incurred to install a traditional gas boiler. The cost of traditional network connections and infrastructure (for gas, electricity and water) do not usually constrain the development process or costs.

A1.1.6.2 Are the costs of energy network infrastructure and connections a significant factor in the design of the development as a whole? Are there any circumstances where they become more significant?

The existing network infrastructure may be inadequate to suit the needs of the proposed new development. An infrastructure upgrade adds substantial costs to the development and could be too high to justify depending upon the number of plots on that particular site. North Ayrshire Council have had to provide new substations at their Flatt Road and St Michael's Wynd projects but the number of units at both of these sites justifies the cost.

The existing energy network infrastructure may also not be able to take any additional input, such as from solar panels where the unused power cannot be fed back into the main grid. Other items to be considered include EV charge points, again having an impact on the existing energy network and whether it is capable of providing such points for every dwelling within the development.

A1.1.6.3 How will these costs be impacted by the need for low carbon / zero emissions heating technologies such as heat pumps? Are there any wider impacts of switching to these technologies?

The main impact of the need for low carbon / zero emissions heating is the additional cost of these technologies, when compared to those for traditional heating systems.

Some of the heat pumps have other issues such as noise pollution, which may not be appropriate for more densely populated developments. Ongoing maintenance costs for low carbon heating can be an issue, as gas boilers offer a 10-year warranty. Running costs also need to be considered. Electric boilers, for example, can be cheaper to install than gas boilers but running costs are higher. Some of the renewable energy solutions are only suitable for new build homes as they are so well insulated. A lack of trained engineers to maintain systems and maintenance costs is also a potential issue.

This may improve with time as more companies invest the time and money to develop technology and train their engineers.

A1.1.6.4 What data do you calculate or estimate for the design of heating solution for the properties?

The council employ the services of mechanical and electrical design consultants to carry out heat loss calculations and heating system / plant design adhering to their specified criteria which is Scottish Building Standards, Section 7 ‘Silver Levels 1+2 of Sustainability’. This details the required heat loss / u values the council must design to and the SAP calculation determines the amount of solar generation / technologies they require to provide to meet the design requirements. Designing to the Silver Levels 1+2 will reduce the size of the radiators required as the heat loss / u values they design to are very energy efficient. Also, the air tightness they currently design to reduces and limits the carbon emissions from the dwelling.

The Council also undertakes Dynamic Simulation Modelling calculations, where appropriate, to identify the most sustainable technologies for their new build developments.

A1.1.7 Affordable Homes survey response: Caledonia Housing Association

A1.1.7.1 When you are developing housing, what heating technologies are generally installed today? What drives this decision?

The vast majority of Caledonia Housing Association’s heating systems use a gas boiler. This decision is driven by a number of factors including;

- Existing maintenance regimes
- Ease and relatively low cost of installation
- Ease of use for customers

A1.1.7.2 Are the costs of energy network infrastructure and connections a significant factor in the design of the development as a whole? Are there any circumstances where they become more significant?

The costs of energy network infrastructure and connections has no impact in the design of the development, unless they are providing homes in remote rural locations where infrastructure costs would come into play.

A1.1.7.3 How will these costs be impacted by the need for low carbon / zero emissions heating technologies such as heat pumps? Are there any wider impacts of switching to these technologies?

Whilst the technology is relatively new there will be impacts on the cost of installation and maintenance of zero emissions heating technologies. As the technology becomes more widespread the costs will be lower, as seen with solar panels for example. The wider impacts will be the maintenance plans and finding suitable and competent contractors to take on this role. Also, education for customers and staff around the new technologies will be important and support and training will be required.

A1.1.7.4 What data do you calculate or estimate for the design of heating solution for the properties?

Caledonia Housing Association usually leave it up to the contractor to calculate in line with their brief around the energy standard the property is expected to achieve.

A1.2 Information from Ramboll

Ramboll is an engineering, architecture and consultancy company that have been commissioned by the Scottish Government to undertake a related project; Costs of Zero Carbon Heat Research, which explores the operational costs and other implications of operating alternative heating technologies.

As part of this project, Ramboll have developed scenarios that describe a range of different development types to be considered in their analysis. Three of these case studies are domestic developments, with the others covering commercial or other scenarios. The three housing scenarios are aligned with the three modelled case studies described in this report. Refer to Appendix A2 for more information.

Ramboll also undertook stakeholder engagement as part of their project, and with the consent of the stakeholders involved, provided notes for three interviews they had with developers including:

- Hjatland Housing Association
- Winchburgh Development, who are a land developer currently working with CALA Homes
- Eldon Housing Association

Hjatland Housing Association, based in the Shetlands, typically install heating technologies with zero emissions at the point of use. This can be either electric storage heaters or heat pumps. There are cases with district heating, which directly imports the heat generated from burning waste from an energy plant.

The island has never had a gas supply, so all properties are fitted with electric heaters. The current preference is to use electric storage heaters as they offer the best value and have lower capital and maintenance costs as well as cost to the tenants. Their tenants generally prefer storage heaters. Heat pumps are over three times the capital costs and need replacing every few years. Air-source heat pumps supply the heat only and the properties have separate hot water cylinders for hot water. They have considered solar thermal heating and solar panel electricity generation, but this would not be practical in the Shetlands. Due to the current building regulations and meeting their SAP calculations for new builds, they have been unable to install storage or district heating.

Eldon Housing Association has built a few low carbon homes, particularly on off-gas systems, and are transitioning towards installing air-source heat pumps combined with solar panels, which tends to work quite well for their developments. As they see the direction of travel towards phasing out gas, they are considering installing air-source heat pumps in favour of gas boilers. They still have storage heaters and are fitting new ones but recognise that is not the right thing to do, as they are less environmentally friendly.

A1.3 DNOs

The two DNOs in Scotland, Scottish Power Electricity Network (SPEN) and Scottish and Southern Energy Networks (SSEN) were interviewed, and both provided additional contributions to the project in the form of information and data to support case study development.

A1.3.1 Interview: Scottish Power Electricity Network (SPEN)

A1.3.1.1 Process for establishing energy infrastructure for new build developments

The process from SPEN's point of view is provided below.

- The developer / IDNO / ICP will contact the DNO for a connection.
- If a full connection request is made by the developer:
    - The DNO will quote for the full works, including the onsite network infrastructure, as well as a DNO point of connection and any reinforcement. The DNO will use their own calculations on the size of connections needed based on the site plans and their own diversity assumptions.
    - The developer accepts the connection offer.
    - The DNO builds the network to their standards and provides a connection.
    - The DNO operates the network as part of their wider network.
- If a point of connection request is made by an IDNO or ICP
    - The IDNOs / ICPs will have calculated the required connection capacity, taking into account connected technologies.
    - The DNO designs the network and provides a point of connection offer. They design the connection to the size and information provided all the necessary information has been submitted and may not have visibility of the design of the development itself.

- The developer / IDNO / ICP interacts with the DNO to arrange a point of connection quote, design approval and implementation.
- The ICP builds the network.
- The DNO provides the point of connection.
- In some cases, the DNO may adopt the network that the ICP builds. If the DNO is adopting, then the network must be in line with their network standards and will be part of an adoption agreement.

There may be multiple ICPs / IDNOs applying for the same connection before the developer has selected the chosen contractor. This means that the DNO may be doing multiple design and assessment studies for the same project. The results cannot be shared between the applicants, due to commercial sensitivities, and the submissions might be slightly different due to differing assumptions. This adds to the work for the DNO associated with that development.

A1.3.1.2 Main drivers for the cost of network connection for developments, and who pays for them

DNOs are obligated to provide the least cost, competent and capable connections in their connection offer to provide the capacity and requirements stated in the connection application. This might not mean the least cost for the customer as, for example, the route might require going over private land, where wayleaves can be costly and take time. These are indicative costs only.

DNOs generally do not size their connections to take account for larger future load, or future proof for communications infrastructure unless there is an agreement with the customer.

The scenarios for paying for a connection are as follows:

- Customers who ask for additional network capacity will pay for it.
- Customers pay a proportion of any wider works (reinforcement work) while the rest is socialised to the public.
- Socialised costs are very small per customer, and there are wider societal and energy system benefits. Socialised costs are spread across the customers for that particular DNO.

A1.3.1.3 Impact of zero emissions heat technologies on connection process

The impact on costs brought by electric heating will be socialised to the public, with societal and energy system benefits. This needs to be carefully considered to make sure it is fair and valuable for society. The impact of low carbon technologies on top of traditional load will present new challenges to the DNOs.

A1.3.1.4 Related innovation projects

A list of related innovation projects SPEN are involved in is provided below

- SPEN are considering installing and owning EV chargers (trial licence exemption) which will allow building of knowledge about EV charging loads. In the future, this might be a build and sell opportunity for SPEN.
- SPEN are using monitoring to understand what the loads look like (how they add up, what the diversity is, and what this means for the peak demand).

They are working with CALA Homes, SSE and E.ON to understand how electric heating and low carbon technologies impacts the network. SPEN are also working with a number of developers in an area of weak network, where the developers want to install heat pumps, but where the reinforcement requirement would be prohibitive. They are working with the developers and the IDNO to identify alternative solutions to accommodate them, such as a behind the meter approach.

- SPEN's other major aim is to focus on the service provided to the customer, and to provide solutions that can last the lifetime of 30 or 40 years.

A1.3.1.5 Other points raised

Key messages are listed below.

- There is a recognition that the building fabric should be the first priority to address in order to make homes more energy efficient.
- Heat cannot be seen in isolation. There is a need to consider EVs, different types of load, penetration of technology and comms, which allows people to participate in a new energy market.
- Changes to need to be incentivised or mandated. DNOs are in the perfect position to socialise the costs and mitigate the impact on consumers.
- DNOs cannot be the blocker for innovation and progress.

A1.3.2 Interview: Scottish and Southern Energy Networks (SSEN)

A1.3.2.1 Process for establishing energy infrastructure for new build developments

The process from SSEN's point of view is provided below.

- Customer (in this case, a developer, ICP or IDNO) will submit an application to the DNO for a connection
- The DNO runs studies and provides a quote
    - All full works quotes to developers are convertible to point of connections quotes; the contestable and non-contestable works are itemised, allowing the quotes for contestable works to be compared with quotes from ICPs.
    - Smaller connections have to be quoted and returned to the developer in 5 working days, while larger developments can last up to 65 days. The quote offered to the developer is valid for a period of up to 3 months.
- The customer accepts the quote
- The DNO contacts the customer to discuss carrying out the project, for example, the start and end date will be agreed and will tie in with the onsite works.
- The customer develops the project, and the DNO provides the agreed works
    - Some ICPs are authorised to undertake work on DNOs network at low voltage, meaning that there could be very little DNO input, unless reinforcement is required. ICPs can design and connect with authorised personnel.

  - Small jobs must be completed within three months, while larger projects will have up to a year to finalise works. This is to ensure that there is not significant network capacity being reserved for projects that do not happen.

A key point to note is the Second Comer Rebate. If a developer pays for reinforcement, and another developer comes along later (within 10 years) who also wants to use that capacity, then the second developer gets a 'second comer' charge, which is repaid to the party who paid for the original investment.

Where an IDNOs is operating an existing local network connected to the DNO and has additional connections within their network, they have to apply to the DNO for a change in connection terms, which might require reinforcement.

A1.3.2.2 Main drivers for the cost of network connection for developments, and who pays for them

The main drivers for the cost of new infrastructure is listed below.

- Location
- Energy requirements of the new development
- Availability of existing assets to provide the capacity required for the new connection
- The distance between the site and the point of connection

The party who normally pays for the infrastructure is as follows.

- The developer will pay for extension of assets
- Non-contestable work is carried out by SSEN and is paid for by the developer
- Reinforcement work is apportioned between the developer and the rest is socialised between the DNOs customers.

The rules that determine how to apportion reinforcement costs might be changing in the next price control period for the DNOs. For example, the amount a DNO can recover from its investment may vary for each geographical location, thereby factoring in localised DUoS charges. The amount recovered is more likely be focused on larger voltage levels. The changes are being brought in through the Significant Code Review, an Ofgem-led project that assesses how network charges should be set and recovered in Great Britain.

A1.3.2.3 Impact of zero emissions heat technologies on connection process

For establishing size of connections per plot, SSEN does not generally consider any expected future uptake of low carbon technologies and the impact on their connections. They assess the projects as presented to them in the connection request. However, it would be possible to identify weak spots (e.g. small diameter cables), which could be upgraded to cope with additional load on the network. Part of the next Ofgem price controls process has been around strategic investment, with a particular focus on where increased load is likely to be and identify the electrical assets that require an upgrade. This is all factored into how SSEN and other DNOs quote for a design.

Designers use a point of connection matrix to input customer requirements at the site, which would give the DNO an idea about the diversified load they have to design to. This might be more often used for smaller domestic developments rather than at large sites. The ICP, working on behalf of the developer, will have factored in diversity calculations at the site before they approach the DNO for a connection offer. This allows the ICP / developer to get what they requested.

Power quality issues are not known at domestic level; however, studies have been carried out at larger levels. Connection offers for larger sites will have constraints around harmonics and other power quality issues.

A1.3.2.4 Other points raised

Generally, developments will be a mixture of heating technologies, more than all low carbon heating. Making the transition to 100% renewable heating will have a significant impact on the network's performance. All development sizes will have similar engineering issues, but the real difference will be driven by the location of the site, and the existing network assets in the area at the time.

SSEN have stopped using smaller sizes for some assets. This is driven by the convenience of managing assets and procurement, but also has advantages in future-proofing the network.

A1.4 IDNOs

A1.4.1 Interview: GTC

GTC is the UK's leading independent utility infrastructure provider who delivers cost-effective gas, electric and water networks along with sustainable solutions to new housing and commercial developments.

A1.4.1.1 Process for establishing energy infrastructure for new build developments

The process from GTC's point of view is provided below.

The developer will establish the project and its requirements and will either engage directly with the IDNO or ICP.

In the case where the developer engages directly with the ICP the process is as follows:

- The developer and ICP collaborate on the design of the network.
- The ICP forms a commercial agreement with the IDNO to adopt the assets. The IDNO will likely agree an asset value to adopt the assets. DNOs will not offer this, hence why many ICP developed networks will be adopted by IDNOs.
- A connection request is submitted to the DNO. The connection request process with the DNO is the same for an ICP as any other customer.
- The ICP builds the network. Assets must be up to the standards of the network operator who will be adopting the assets.
- The DNO provides a point of connection to the network.
- The IDNO adopts the assets.

- The IDNO operates the assets going forward.

In the case where the developer engages directly with the IDNO, the process is as follows below:

- The developer and IDNO collaborate on the design of the network. The IDNO will work with the developer to see what they think their load will be (GTC provide support here, particularly with low carbon technologies and diversity assumptions).
- The IDNO applies for a connection to the DNO network. The point of connection could be on the low voltage, high voltage or extra high voltage network. The DNO will give characteristics of the connection so that the network can be designed within limits.
- The IDNO builds the network, potentially engaging an external ICP or using an in-house team. Some larger works or works requiring specialist feasibility studies etc. might be contracted out.
- The DNO provides a point of connection to the network and may wish to inspect any assets they are adopting. Inspection depends on the authority that the organisation has (GTC have self-authorisation). If the IDNO establish a new substation, then the high voltage side will need to be adopted by the DNO, which the DNO will want to inspect before adopting.
- The IDNO operates the assets on an ongoing basis.

Costs are covered through two processes.

- GTC will have a commercial agreement in place with the developer for the installation of new equipment.
- Ongoing operation and maintenance costs of the assets are recovered through DUoS charges.

The only difference between the gas and electricity process is that there are fewer GDNs than DNOs.

A1.4.1.2 Key difference between Independent utilities and DNOs / GDNs when connecting and operating energy networks for domestic developments

The key differences between independent utilities and DNO / GDNs are listed below:

- Independent utilities can be multi-utility, supplying a range for services such as electricity, gas, water, communications, and increasingly district heating, which can give commercial and practical advantages.
- The independent utilities are not area bound. This means that there is one approach across the whole GB. Independent utilities tend to stick with industry standards for best practice, while the DNO / GDNs have their own standards.
- They cannot receive incentives under ED1 or ED2, such as innovation allowances, health indices or load indices
- IDNOs do not need to publish Long-Term Development Statements (LTDS).

A1.4.1.3 Main drivers for the cost of network connection for developments, and who pays for them

The main drivers for the cost of network connection are listed below;

- **Spare capacity on local network:** Spare capacity on the network means that there are circumstances where the costs are different. For reinforcement needed upstream, a contractual arrangement is agreed with the host DNO. For new transformers, the developer is only charged a proportionate cost depending on the released capacity that is needed at the development.
- **Practices of connecting to the DNO:** E.g. for SPEN, a connection with more than 200kW of export requires a TO application.
- **Connection voltage level:** If there is not enough spare capacity at one voltage level, then they will connect one level up, which means that the level of infrastructure will go up.
- **Design and construction programme of the site:** GTC wants to run the development in the most cost-effective way, but the design of the site might prevent this.

GTC will communicate with the developer on the costs of the infrastructure, and the contribution they will make. Going forward, DUoS pays for the operation of the network.

A1.4.1.4 Impact of zero emissions heat technologies on connection process

The impact that heat technologies has on the network is driven by the developer. Low carbon heating cannot be considered in a silo because, for example, the building fabric and installed technologies means that the energy consumption of new homes is quite different from old homes. This includes low carbon heating, EV charging, solar panels, efficient appliances, as well as insulation and building fabric changes.

GTC owns and operates approximately five heat network energy centres, and heat networks are becoming more standard for new developments.

There are some power quality issues associated with LED lighting, and to a smaller extent, from heat pumps. This is low at the moment, but low carbon technologies can have an impact on power quality. Each individual asset passes requirements, but together the effects can combine. A development that will include all low carbon technologies and LED lighting will result in power quality becoming a major issue. GTC highlighted they need better information about the network in order to manage this.

The existing gas network owned by GTC will continue to supply existing customers going forward.

A1.4.2 Interview: Independent Networks Association (INA)

The INA is an industry body which represents the voice of the UK's independent utility networks. Independent utility providers are organisations that provide Multi-Utility services, such as electricity, gas and water supply to their customers. IDNOs are represented within this body.

A1.4.2.1 Process for establishing energy infrastructure for new build developments

A developer will issue a tender for energy infrastructure onsite. The ICP determines which operator (DNO or IDNO) will be adopting the equipment. An ICP may speak to multiple IDNOs to get an asset value for their assets. This can happen at any stage of the process but is likely to happen at tender stage so that the ICP can base their offer on the asset value they receive from an IDNO. The ICPs develop the initial design and respond to the tender. An ICP is typically geographically based and has strong relationships with the developers. Several ICPs may go to separate IDNOs to get quotes for their assets. The developer selects the ICP based on their tendered options and begins working with the ICP on the design of the network.

If the ICP decides that the DNO is adopting the assets, the process is as follows:

- The ICP interacts with the DNO to arrange a point of connection and adoption agreement. This is very rare as most new build developments are adopted by IDNOs. There are some cases where the DNO would do some of the connection work instead of the ICP, but this is very uncommon.
- The ICP builds the network.
- The DNO adopts and operates the network as part of their wider network.

If the ICP decides that the IDNO is adopting the assets, the process is as follows:

- The ICP interacts with the DNO to arrange a point of connection quote, design approval, and implementation. Even though the ICP is applying for this connection this is still an agreement between the DNO and IDNO.
- In parallel to above, the ICP interacts with the IDNO to arrange an adoption contract and design approval. The ICP will be paid for the assets that the IDNO adopts.
- The ICP builds the network.
- The IDNO adopts and operates the network.

Network design and equipment specification must be in line with the requirements of the adopting network operator. This will vary between operators (IDNOs and DNOs). The ICP needs approval from the IDNO to move on to each phase of the work by regularly inspecting the assets they will be adopting. The IDNO is responsible for all connection operations after the network is built and has emergency service protocols and first emergency call outs to respond to faults on their network. The DNO can provide emergency services to the IDNO and secure capacity to feed their network.

There are multiple routes by which energy infrastructure is established for a new development. The process described above covers one case where the developer issues a tender to lead design and development of infrastructure. Alternatively, the developer might contact the DNO directly, in which case there is no ICP or IDNO involved.

A1.4.2.2 Key difference between Independent utilities and DNOs / GDNs when connecting and operating energy networks for domestic developments

In terms of the end user there should be no difference in relation to who owns and is supplying the energy needed. From a commercial point of view, an independent utility provider (gas & electric) may offer an asset value to an ICP to adopt their assets to secure the work that the ICP has agreed with the developer. DNO and GDNs do not have the option to offer asset values.

In some cases, DNO / GDN network data is not made available to IDNOs (particularly from higher voltage / pressure levels). Independent utilities only have access to their own network data.

A1.4.2.3 Main drivers for the cost of network connection for developments, and who pays for them

The location of the site will have an impact on connection cost, as well as available capacity. House buyers would normally pay for a simple connection, which is an extension of an existing connection. If reinforcement is required, then there is a test that is used to determine how much each respective party pays towards the work involved. If the ICP has to pay a proportion of the costs, then they would look to charge the costs to the developer. This is a commercial call that the ICP would make.

A1.4.2.4 Impact of zero emissions heat technologies on connection process

Different low carbon technologies are presenting challenges which needs to be considered. EVs and solar panels are already being looked at as part of the design document. The type of technology and load consumption information is needed as well as an indication on any future loads.

The plan is to keep using gas at existing sites unless changes occur. The INA believe there is room for hydrogen and heat networks as an alternative for heating as well as electric.

When considering low carbon technologies, the following aspects need to be considered:

- Operational and maintenance costs
- Space in the home to accommodate the technology
- Effectiveness and comfort levels.
- The potential need for gas supplies for secondary heating (i.e. fires) and for cooking.

A1.5 ICPs

Energetics are an ICP that designs and builds utility network connections in Scotland, North Wales and the North of England.

A1.5.1.1 Process for establishing energy infrastructure for new domestic developments

The process for establishing new energy infrastructure from Energetics point of view is the same as the one from the Independent Networks Association.

For small projects (less than 50 homes), the developer may choose to organise connection directly with the DNO, but most large developments will use an ICP. Generally, the developer will select the heating technology and other design aspects of the development, independently of the ICP. The ICP business is highly commoditised, with many developers simply awarding their project to the highest bidder.

A1.5.1.2 Main drivers for the costs of network connection for developments, and who pays for them

Developers will generally award the cheapest price for the design of the network. If there is no gas, developers can consider LPG. The main drivers for the cost of infrastructure is provided below.

- **The load that is requested and if there is any generation export**
  - This will dictate if work is required at high voltage levels (which is more onerous) or just low voltage
  - This will dictate reinforcement requirements
- **Distance to the point of connection**
  - What you are crossing - Water crossings, major road crossings, cobbles or block roads
  - The need to deal with other landowners
  - This can drive the cost per plot which might be prohibitive. E.g. if there are relatively small numbers of low-cost social housing plots, and the distance to site is high
- **Diversion costs**
  - Existing circuits that cross a development (e.g. undergrounding overhead lines or diverting cables that are in the way of building works), are generally re-routed by the ICP within the timelines of the development (which might require a phased approach). If the DNO undertakes it, then the costs are passed on to the developers

Asset costs are paid for by the ICP, and this this gets passed on to the IDNO. IDNOs have a calculator that tells them the likely income per plot over the next few years of operation, and they generally offer the ICP a part of this which is then passed onto the developer to reduce the infrastructure costs. The IDNOs do this to secure the network for adoption. DNOs do not offer asset value.

ICPs have a minimum of three parties to interact with:

- DNOs to ensure that the point of connection and the high voltage infrastructure meets their requirements
- IDNOs to ensure that the low voltage network meets their requirements
- Developer, who is paying for the infrastructure for their development

A1.5.1.3 Impact of zero emissions heating on connection process

When the heating technology is electric, it will result in a higher load, which will have many implications on the cost of the infrastructure such as:

- **Higher onsite costs through more infrastructure**
  - Higher rated cables
  - More substations

  - Possibility for higher connection voltages, meaning the need for higher voltage infrastructure.
- **Higher offsite costs**
  - More reinforcement might be needed on the DNO network,
  - It might mean that the point of connection is in a different location, or a higher voltage, which might be further away from site.

Similar impacts are observed with EV charging points; however, for smart charging, it is assumed that it will not add to peak demand of the site.

The impact of not needing gas is that the work contracted to the ICP is reduced, and they would no longer get a gas asset value. This results in lost revenue for an electricity-only site. The cost saving for the developer of not putting in the gas might be outweighed by the higher cost of a low carbon heating technology.

Considerations that need to be made for sizing connections for low carbon technologies are listed below.

- Diversity assumptions are indicated by the asset owners. They will generally vary load and diversity requirements between different building types (DNOs might have a standard value for a wide range of homes).
- Diversity assumptions made might not allow for futureproofing against load growth. They will generally build to what the owner dictates.
- Some requirements are vague. Making allowance for EV charging can be interpreted in different ways but there is increasingly specific guidance from local authorities (and passed on by developers)

A1.5.1.4 Innovation projects

Innovation projects around heat / low carbon technologies are as follows:

- Energetics are involved in installing EV, solar panels and heat pumps in Scotland.
- A project focussed on Queens Quay, Clydebank for District Heating. The client has to pay for a district heating network, and there is no asset value offered on this. District heating is unregulated, and IDNOs do not necessarily have an ownership model for this yet.

A1.6 Heat Pump Manufacturers

A1.6.1 Interview: Mitsubishi Electric

Mitsubishi Electric are a manufacturer of cooling, heating and ventilation solutions, including air source heat pumps. The interview focused on the heat pump units they offer, and the barriers and benefits they see in adoption of heat pumps into new build developments.

A1.6.1.1 Zero emissions heating landscape

The market changed for off gas grid developments when the new build standards came out in 2015. This accelerated the adoption of heat pumps, and Mitsubishi

Electric is now starting to see some social housing developers considering heat pumps as the primary solution as it is zero emissions and low cost for the tenants. Some regions are used to having heat pumps in their housing stock, and it has become a proven default which future-proofs their housing stock. .

Private developers are more likely to favour gas if available due to costs. In off gas areas, certainly in the highlands and islands, they will install heat pumps. The Scottish Borders are beginning to do the same, and the central belt is lagging behind.

Developers are not thinking in terms of zero emissions heating options, they are trying to meet the building standards in the most optimal / cheapest way.

The challenges and barriers of moving towards zero emissions heating are as follows:

- Existing infrastructure and industry around gas supplies.
- Perception of heat pumps, particularly within the larger developers, and homeowners.
- Perceived cost increase for putting in a heat pump. If you compare the cost of a heat pump to the cost of a gas boiler, you should include the cost of the gas system and connection.
- Lack of understanding of the DNOs. Mitsubishi are seeing significant regional differences in how heat pumps are treated, even within DNOs. Some regions understand the landscape, and some do not. There is no standard methodology by which a DNO will accept or reject an application based on heat pumps. Mitsubishi has been working with the DNOs across the UK to help them understand the operation of a heat pump, and their diversity.

Mitsubishi Electric's conclusion on the level of diversity of heat pumps is as follows:

- Monitoring has shown that you can assume 30% to 60% diversity. Mitsubishi has looked at retrofit and are still finding a diversity of 30%. In other words, across a wider group of heat pump heated properties, the average heat pump electrical load per house is 30% to 60% of its maximum capacity.
- This is because most of the time, heat pumps are not heating hot water (which would be full capacity), and most of the time, the heating will only use a small proportion of the capacity.
- Heating based on heat loss calculation will very rarely come to 4kW. Therefore, it will not need the full amount. It is much more likely to use 1kW to 1.5kW as its electrical input to provide heating. Then there is diversity between units.

A1.6.1.2 Choice of heating technology commonly used today

The market can provide solutions that can deliver the heating requirements of a home no matter what the property type is. The following describes the range offered by Mitsubishi Electric.

- Minimum heat pumps sizes start at 4kW unit (electrical input of up to 2kW) designed to focus on hot water as the prime driver. They have a seasonal efficiency of 3.5 and are typically installed in individual houses and flats up to 3 or 4 bedrooms, or highly insulated homes, where the demand is driven by hot water above heating.
- The main range of heat pumps for domestic heating includes 5kW, 6kW, 8kW, 11kW and 14kW units. These units are designed for heating, and the heat pump size can be matched to the heating requirement of the property and this is what the range provides. Some properties have multiple units installed which are cascaded together, optimising each unit to be as efficient as possible by matching the load.
- A large range of heat pumps can be air source rated at 43kW, and a large water loop system rated at 60kW. These can be cascaded together, covering projects of greater than 1MW (up to 3MW on existing projects). They often serve shared heating systems, including hot shared heating loops, or ambient loops.
- Intelligent controls can come with heat pumps installations
    - 4kW and 5kW to 14kW heat pumps have intelligent controls, which are simple, easy to use interfaces within the property, which learns about the thermal behaviour of the space and makes decisions about how to operate in order to meet the heating requirements.
    - An app can be used which pairs to the WIFI, and allows control of the heating system, provides heating data, and notifies the user of any issue. Additionally, when a homeowner calls up with an issue, this system allows ~70% of the issues to be solved remotely through diagnostics. No additional fees are incurred for the service.
    - Through Smart Grid Interface, heat pumps have the ability to accept inputs from batteries, solar panels and demand side response notifications for example, which allows them to manage hot water and heating requirements.

The size of the unit for each property is driven by the heat loss calculations. This will help to inform electrical requirement, fuse size and information required by the DNO. Note that the 4kW unit is used a lot (60% of the time), particularly for affordable housing, and typical small / moderate sized homes. Larger private housing might use 8kW and 11kW, with the occasional larger unit. If larger homes are specified to a high standard of insulation, then the 4kW may serve the heating requirements.

The heat pump location and noise it makes in a property is an important aspect to consider.

A1.6.1.3 Relationship with developers

Mitsubishi Electric offer a service from design to installation of heat pumps, and then ongoing support.

- Specification team engage with developers and stakeholders, provide education on heat pumps, undertake desktop designs on sizing of units and running cost expectations, and once projects are secured, provide detailed designs.
- They provide training for staff, open days for potential homeowners, engage the developers within site as well as supporting installation and commissioning.
- Once installed they provide support with services and ongoing operation.

In the wider market for Heat Pumps other suppliers typically do not offer a complete offering for developers, and there is a varying quality of products available.

A1.6.1.4 Impact of zero emissions heating

The cost implications are as follows:

- Oil boilers and heat pumps are cost neutral.
- In comparison to gas boilers, there is typically a 20% increase in cost through installation; however, factoring in that the gas network and connection will not be needed at all can save the developer / homeowner a lot of money and initial investment.
- Operational costs with gas and electricity costs at today's prices is a factor. The operational costs are comparable for new builds. Smarter heating controls can reduce the costs further for electric heating.
- Maintenance costs are comparable. This is influenced by economies of scale for maintenance resource, training and technical expertise.

The practical implications are as follows:

- Many of the skills needed for installation and maintenance of heating technologies can be provided through training.
- Skills and understanding are needed in order to size heating technologies correctly.
- User interaction is vital. The system has optimised controls and is designed to be intuitive, but users need support in using the systems correctly. Where the installers have provided the appropriate information to the homeowners about how to use it along with proper training, fewer issues are seen in the future.

The issue of harmonics is already well understood as part of the sector, for example in air conditioning. For the heat pumps, this knowledge is built into the design. The units have filters, and therefore the issue is limited. This should be the case with most of the major manufacturers, as long as they are held to the standards.

A2 Case study report

A2.1 Context and overview

The aim of the technical modelling task within this Research into Electricity Network Constraints and the 2024 New Build Heat Standard project is to explore the connection costs for case study examples given a range of traditional low carbon heating options.

The case studies were selected to explore the breadth of applications and situations that are of most interest to the Scottish Government, including a range of development sizes, locations, and technologies (heating and EV charging). The aim was to define case studies based on real data where possible, using assumptions and estimated data to fill in gaps and to ensure the breadth of examples are explored. Further to this, case studies were designed to align with the scenarios developed by a separate project commissioned by the Scottish Government; Costs of Zero Carbon Heat Research carried out by Ramboll, which explores the operational costs and other implications of operating alternative heating technologies. It is hoped that aligning the case studies will allow the Scottish Government to gain increased value from each of the projects and their findings.

The following sections details the modelled case studies and development examples.

A2.2 Modelled case studies

The project includes three case studies that are formed from modelled developments (i.e. the developments are not real projects), using data and information about real projects and examples gained from stakeholders. This approach was used to ensure the full range of case study examples can be included.

The modelled developments include:

- **Private housing development:** 300 homes made up of a mixture of 3, 4 and 5-bedroom homes, and 20% affordable homes, in the North Glasgow area. This is a suburban location, with a strong local electrical network. The modelled network capacity is based on the Balmore B/ village substation, which was identified from SPEN’s heat map [24].
- **Social Housing Development:** 60 homes made up of 30 semi-detached houses (3, 4 and 5-bedroom), and 30 flats (1 and 2 bedrooms, 3-storey), in the Dunfermline area. The network in this area is highly constrained, with very little remaining capacity before significant network upgrades are required
- **Small Scale Rural Development:** Small development of 10 detached homes in a remote rural area. The modelled network capacity is based on the Newcastleton substation near the Scottish border with England, which was identified from SPEN’s heat map [24].

A2.2.1 Modelled case study definition and assumptions

The case study modelling for the development of electricity infrastructure is based on the following key concepts:

Technology assumptions: The case study modelling includes understanding the impact of different technology options, including heating technology options and the inclusion of EV charging, on the energy infrastructure and connection costs of the modelled developments.

Table 8-1 shows the technology assumptions used for each technology and each size of house.

Table 8-1 Modelled case study technology assumptions

Technology	Assumption	Source
Gas heating	No electrical load. Gas load is assumed to be approximately 9kW per property.	Example gas heated sites provided by project stakeholders
Storage heaters	Assumes storage heating systems installed in each home, with the following electrical ratings: • 1-2 bed homes have storage heating systems which draw 5kW of electricity on full load. • 3-4 bed homes have storage heating systems which draw 8kW of electricity on full load. • 5+ bed homes have storage heating systems which draw 16kW of electricity on full load. It is assumed that hot water load is provided by a 3kW electrical emersion heater, managed to minimise peak load.	SPEN ADMD calculator assumptions
Heat pumps	Assumes that an air source heat pump is installed in each home, at the following electrical ratings. • 1-2 bed homes require a 5kW heat pump, which draws ~2.4kW of electricity on full load. • 2-3 bed homes require an 8kW heat pump, which draws ~4.7kW of electricity on full load. • 5+ bed homes require a 16kW heat pump, which draws ~6.5kW of electricity on full load. It is assumed that hot water load is supported by an additional 3kW electrical emersion heater, which is managed to minimise peak load.	SPEN ADMD calculator assumptions Note – heat pump sizes are quoted in kW for heat. The electrical load is lower than the heat
District heating	Assumes that a district heating system will provide space and water heating across the development. This is fed by bore hole ground source heat pumps and a thermal store. Depending on design, an additional boiler (biofuel/hydrogen) may be needed to support heating load on rare extreme cold periods. Heating load is assumed to be 5kW for 1-2 bed homes, 8kW for 3-4 bed homes, and	Queens Quay case study information [10] DECC Assessment of UK Heat Network costs [28]

Technology	Assumption	Source
	16kW for 5+ bed homes. The electricity demand is adjusted for the efficiency of the ground source heat pump technology and the ability to leverage flexibility to reduce the load at peak times.	
EV Charging	A standard EV charge point draws ~7.4kW on full load. A smart charger will ensure that full load charging is avoided at peak times, therefore only adding ~3.7kW to the peak load of the home.	SPEN ADMD calculator assumptions

Peak load to be connected: This is the maximum demand that a development is expected to draw from the wider electricity network, and therefore drives the design of the connection.

The After Diversity Maximum Demand (ADMD) is the value used to size network assets and drive network design. This value takes into account 'diversity'; the assumption that customers will use their loads at different times throughout the day, and therefore the maximum demand experienced on the network is significantly less than a simple addition of all connected loads. Calculation of diversity is not consistent between stakeholders, and the impact that low carbon technologies (e.g. low carbon heating and EVs) have on this figure is being explored through innovative projects and initiatives. SPEN are producing a tool which calculates the ADMD of a group of properties given inputs including heating technology and the presence of standard or smart charging infrastructure. This tool was shared with Ricardo to support this project and has been used to drive the assumptions of the model.

Table 8-2 below shows the assumptions for peak load for each of the modelled case studies, with each of the technology options. The assumptions for the gas heating, heat pump and storage heater properties are based on the SPEN ADMD calculator, including without EV charging, with standard charging, and with smart charging. These assumptions include the ADMD of the properties as a whole, including appliances, heating and hot water. The ADMD for the district heating case is based on the ADMD for the gas heated case (i.e. the ADMD of the homes without any electrical heating load), plus an ADMD value calculated based on the heat load of the development and altered to account for the efficiency of the ground source heat pump technology and the ability to leverage flexibility to reduce the load at peak times.

Table 8-2: Peak load (ADMD) assumptions for the modelled case study developments

Modelled development	Heating technology	Peak load assumption for the development (kVA)		
		No EV	EV charging	Smart EV charging
Private housing development: 300 3, 4 and 5-bedroom homes	Gas heating	450	1,452	915
	Heat pumps	1,074	2,076	1,539
	Storage heaters	1,863	2,865	2,328
	District heating	728	1,730	1,193
Social Housing Development 60 homes including 30 3 to 5-bedroom houses and 30 1-2-bedroom flats	Gas heating	82	288	183
	Heat pumps	204	410	305
	Storage heaters	300	506	401
	District heating	126	332	226
Small Scale Rural Development Small development of 10 detached homes.	Gas heating	31	94	82
	Heat pumps	80	143	130
	Storage heaters	77	140	127
	District heating	40	103	91

Electricity network connection costs: The costs of connecting additional load to the electricity network is dependent on: the status (available capacity) of the existing network around the point of connection; the distance and complexity of the route between the connection point and the development; and the equipment needed on the site of the development to connect each property.

The available capacity of the local network is variable from location to location; some locations might need substantial upgrades to connect even a small development, while the existing network in another location may be able to support a significant development without the need for upgrade.

The cost to install a cable or overhead line along the route between the connection point and the site of the housing development will depend on the distance and the terrain of the crossing. For example, it is more costly to install cables under a carriageway than in earth embankments. Other examples where costs may be high are crossing water and crossing privately owned land. The required equipment for the distribution network and service connections on the site of the development is largely dependent on the load being connected and is much less likely to be impacted by site-specific factors.

The cost assumptions for the required work to connect the modelled case study developments to the DNO network varies based on the calculated ADMD for the connection. The DNOs publish connection charging methodologies, which provide an indication of the likely cost to install electricity assets [6] [7]. There is significant uncertainty about these costs, which is illustrated by a range of costs provided in the connection charging methodology. For example, the connection charging methodology published by SPEN quotes the cost to install a low voltage substation up to 1000kVA at £54k to £148k. This reflects the site-specific nature of much of the work included. The cost assumptions for electricity infrastructure included in the technical model are driven by the published connection charging methodologies, and therefore reflect this range.

Table 8-3 shows the assumed available network capacity for each of the modelled case study developments, and the network asset requirement assumptions for increasing connection loads.

Table 8-3: Assumed available network capacity, the network asset requirement assumptions, and cost assumptions for each of the modelled case study developments. The costs include installation of the infrastructure.

	Peak Load	Assumed cost range	Notes
Private housing development: 300 homes in an unconstrained network	The network available capacity is high, with no constraints at high voltage substations (primary substation remaining capacity is ~14MW). Connection is to a primary substation over a 30m cable route, beneath a combination of carriageway, footpath and unmade ground.		
	-	£262k - £586k	Onsite equipment includes one substation (<500kVA) and service connections to each property
	> 500kVA	£269k - £607k	Onsite equipment includes one substation (>500kVA) and service connections to each property
	> 1,00kVA	£326k - £763k	Onsite equipment includes two transformers and service connections. Additional planning standards for restoration of load (>1MW)
	> 1,800kVA	£381k - £913k	Onsite equipment includes three transformers and service connections. Additional planning standards for restoration of load (>1MW)
	> 2,800kVA	£436k - £1,063k	Onsite equipment includes four substations and service connections. Additional planning standards for restoration of load (>1MW)

<table>
<tr><th></th><th>Peak Load</th><th>Assumed cost range</th><th>Notes</th></tr>
<tr><td rowspan="4">Social Housing Development
60 homes in a constrained network</td><td colspan="3">The network capacity is highly constrained, with 100kVA of capacity remaining at the high voltage substation, beyond which an additional high voltage primary substation will be required. Primary substations are significant assets, with large costs associated with them compared to lower voltage assets.</td></tr>
<tr><td>-</td><td>£49k - £105k</td><td>Development is connected via the low voltage network, requiring no additional substations. A 100m connection route is assumed</td></tr>
<tr><td>> 100kVA</td><td>£4,167k - £6,376k</td><td>Development requires a primary substation, connected via a 500m cable route and low voltage substation (<500kVA) to supply the homes.</td></tr>
<tr><td>> 500kVA</td><td>£4,237k - £6,536k</td><td>Development requires a primary substation, connected via a 500m cable route and low voltage substation (>500kVA) to supply the homes.</td></tr>
<tr><td rowspan="4">Small Rural Development
10 homes on an unconstrained rural network</td><td colspan="3">The capacity at the high voltage substation is not likely to be affected by this scale of additional load. There is no existing low voltage capacity. Connection is to a primary substation 200m away from the development site, using overhead lines.</td></tr>
<tr><td>-</td><td>£40k - £86k</td><td>Development is connected via a new pole mounted transformer, which is lower cost than a full substation, but has a lower capacity.</td></tr>
<tr><td>>100kVA</td><td>£44k - £92k</td><td>Development is connected via a new pole mounted transformer, which is lower cost than a full substation, but has a lower capacity.</td></tr>
<tr><td>> 350kVA</td><td>£78k - £205k</td><td>Where the load is too large to be supported by a pole mounted transformer, a standard ground mounted substation is required. It is assumed that the service to each property is underground cable.</td></tr>
</table>

Gas network connection costs: The counterfactual case for the technical modelling is individual gas boilers. The heat load and network connection cost assumptions are based on existing project examples provided by stakeholders of the project. The gas load is assumed to be approximately ~9kW per home. The costs per home will vary, with larger developments generally achieving lower per property costs (assumption for the private housing development is £300 to £500 per plot), while smaller developments generally have higher per property costs (assumption for the social housing development and the small scale rural development is £900 to £1200 per plot).

The estimated gas network connection costs are shown in Table 8-4 below:

Table 8-4: Gas connection assumptions for the modelled case study developments

	Assumed gas capacity	Assumed gas network connection costs
Private housing development 300 3, 4 and 5-bedroom homes	2,400kW to 3,000kW	£90k to £150k
Social Housing Development 60 homes between 1 and 5 bedrooms	480kW to 600kW	£54k to £72k
Small Scale Rural Development Small development of 10 detached homes.	80kW to 100kW	£9k to £12k

It is assumed for each development, there is gas network in proximity to the development site, and that no significant extensions or reinforcement is required to connect to the network. It is recognised that this is not the case in all locations – in particular, many rural locations do not have access to the gas network. However, it is the counterfactual case that provides the greatest contrast and challenge to electric heating options.

Heat network costs: The district heating technology requires installation of a heating network, which carries hot fluid to the homes. This is a substantial undertaking, with considerable associated costs. While detailed modelling of these costs is not in scope of this project, it was felt that excluding it entirely would be misleading. Therefore, ballpark heat network infrastructure costs have been calculated, based the DECC Assessment of UK Heat Network costs [28].

Other costs associated with the heating technology: There are several key costs that are not included in the scope of this project, but are important to note:

- **Cost of heating technology appliance:** This is not included in the scope of this project. However, it is noted that there may be significant differences between the unit cost of a gas boiler, an air source heat pump, a storage heating system and a heat exchange for the district heating. This will impact which technology is considered the most appropriate and cost effective.
- **Cost of heat networks:** The district heating technology requires installation of a heating network, which carries hot fluid to the homes. This is a substantial undertaking, with considerable associated costs.
- **Operational costs of the heating options:** The choice of heating technology will impact the associated costs of heating the homes. This should be considered when selecting the technologies.

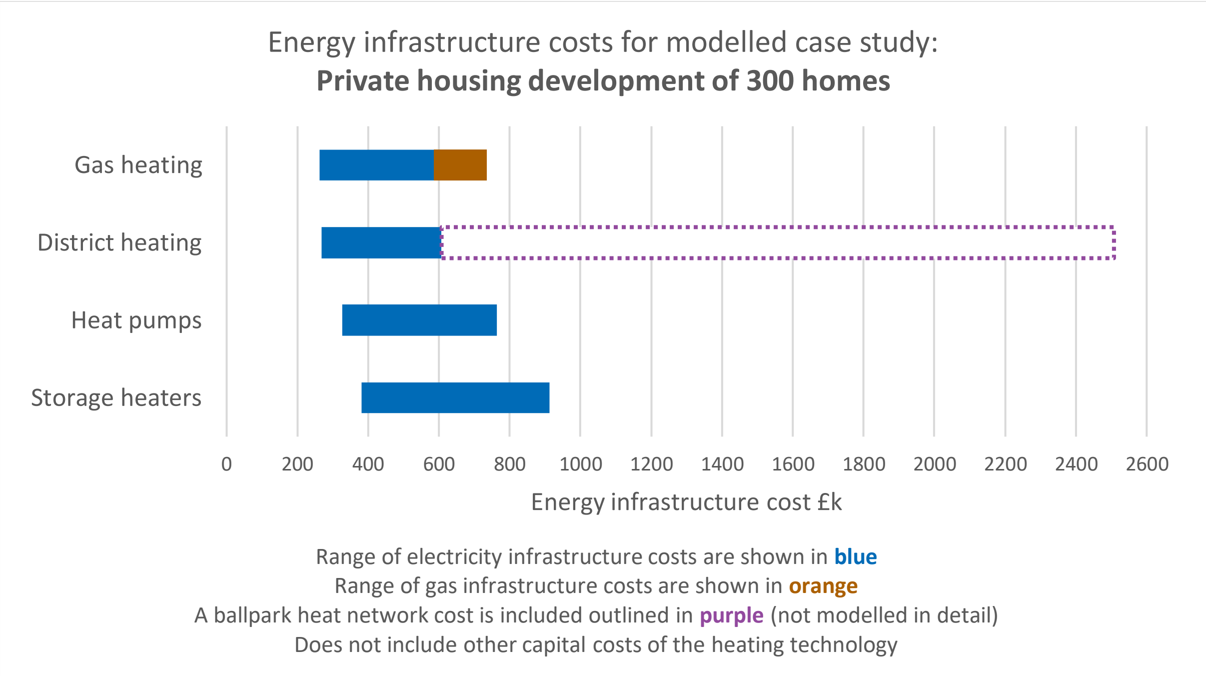
These costs are being considered as part of a separate project commissioned by the Scottish Government; Costs of Zero Carbon Heat Research carried out by Ramboll.

A2.2.2 Modelled case study results

Each of the case study developments were analysed to produce an indicative cost for the energy infrastructure given different technology options (each heating technology, with and without EV charging or smart charging). In each case, it is assumed that the technology option is adopted consistently across the development. For example, in the heat pump and EV charging case, it is assumed that heat pumps and EV charging is installed in every home in the development. In reality, many developments are designed with a mixture of technologies across the homes, however the chosen modelling approach simplifies the results, and tests the most extreme scenario in each case.

Private housing development of 300 homes: The results of the case study modelling for the private housing development case study is shown in Figure 8-1. The chart shows a broad range of costs for each of the heating options, which reflects the uncertainty in the costs due to site-specific circumstances.

Figure 8-1: Energy infrastructure costs for the private housing development modelled case study



The costs shown in Figure 8-1 reflect the following:

- **Gas heating:** This is the case with no electrical heating load. The 450kVA of ADMD electrical load requires a new substation, as well as the associated cables and network equipment. The gas load is 2,400kVA to 3,000kVA, but the gas network costs are modest compared to the electricity network costs.
- **District heating:** District heating enables the heat source to be shared and optimised across the whole development and optimised over time using the

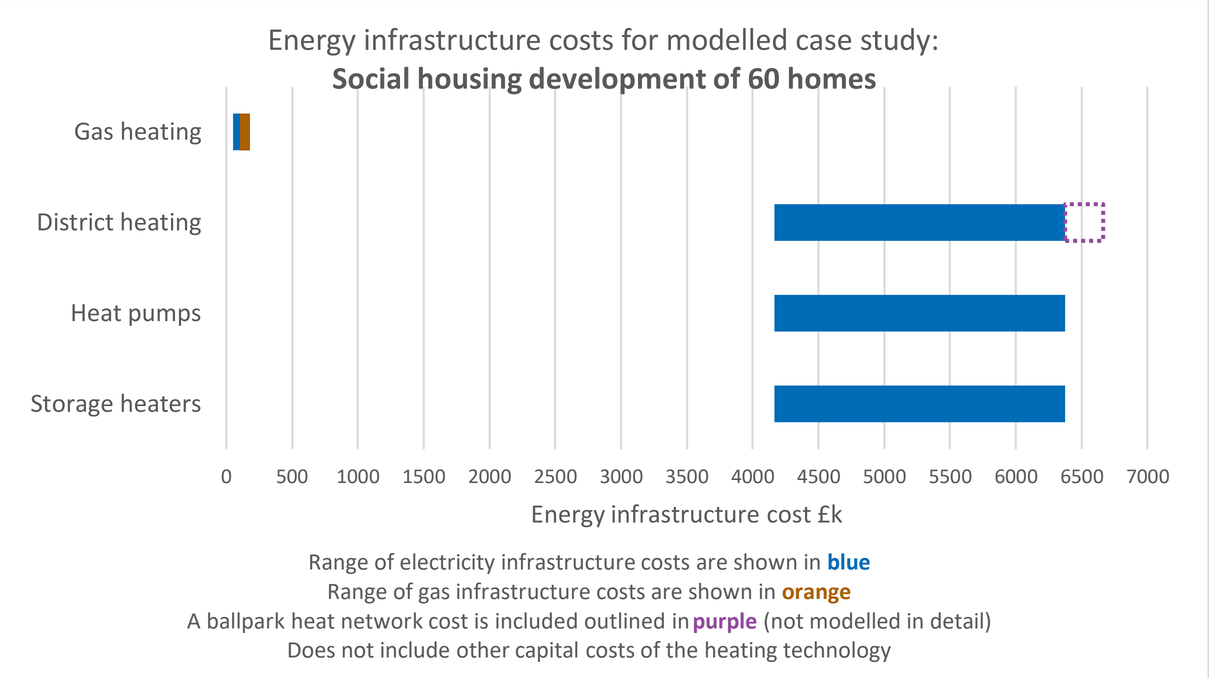
thermal storage built into the system. This allows the heating load to be optimised to minimise the impact on the electricity system. For this reason, it results in only a modest increase in the size of the required electricity network connection (ADMD of 662kVA). For this case study, this increase is low enough not to require additional electricity infrastructure.

- **Heat pumps:** The efficiency and flexibility of heat pumps means that the required increase in the size of connection is lower than that of storage heaters but is a significant increase above district heating (ADMD of 1,74kVA). In this case study model, this results in the need for an additional substation and additional cabling to support electricity network security resulting in an increased electricity network cost compared to the gas and district heating options. The electricity network cost for this case may be comparable to the combined cost of electricity and gas networks combined.
- **Storage heaters**: The storage heaters technology option represent the highest impact on the electricity infrastructure costs. Though they are capable of using flexibility to reduce the impact on peak load, they are less efficient than heat pumps and so result in a larger required electricity connection for the development (ADMD of 1,863kVA). With the assumptions used in this case study, this results in the need to install three substations in order to support the load on the development, leading to increased costs compared to the other heating options.

In each of these cases, these costs are payable by the developer. Much of the work is contestable; it may be installed by the DNO, or by an ICP, and the developer is able to review offers from multiple parties to find the lowest cost option. Where the network is being adopted by an IDNO (if installed by an ICP), then the IDNO may pay an ‘asset value’ to the developer to offset the costs of the installation.

Social Housing Development of 60 homes: The results of the case study modelling for the social housing development case study is shown in Figure 8-2. This case study is located in a highly constrained network, which is capable of supporting up to only 100kVA of additional load without significant additional infrastructure needed. This reflects a real example network condition in the case study location. Connecting developments of over 100kVA will require a new high voltage substation to be installed. As a high voltage substation is a high cost asset, the impact on the costs is stark.

Figure 8-2: Energy infrastructure costs for the social housing development modelled case study



The costs shown in Figure 8-2 are based on:

- **Gas heating:** The ADMD electrical load of this case study using gas heating (so not including any electrical heating load) is 82kVA. As this is below the 100kVA that can be supported on the network without major upgrade, the costs are modest. The gas load is 480kW to 600kW, and the gas network costs are a significant proportion of the overall energy infrastructure costs (electricity costs are £49k to £105k, and the gas network connection costs are £54k to £72k).
- **Electrical heating technologies:** All other heating technologies result in an overall development ADMD electrical load of greater than 100kVA. This results in the need for a new high voltage substation to be installed, at a cost between £4m and £6m. Where this is wholly payable by the developer, this scale of investment is likely to result in the unviability of any new development.

The installation of the new high voltage substation will release significantly more capacity than is needed by this development; a single high voltage substation can be large enough to support thousands of new homes. Therefore, by investing in this new asset, the network will be able to then support other developments as well as this case study.

This changes the context of this case study given the likelihood of other developments connecting to the same area of the network:

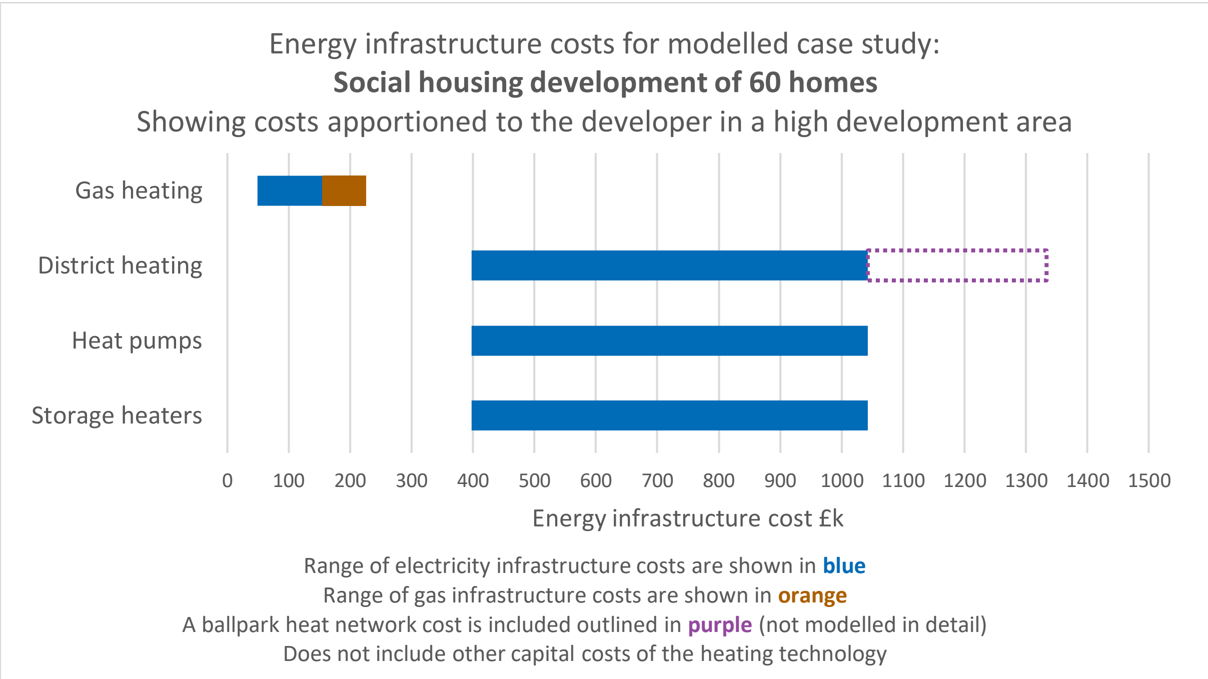
- **High development area:** Where the DNO recognises that there is considerable evidence of wider development in an area where the network is constrained, they can raise this with Ofgem. Developments that need access to capacity in this area may then only pay for the capacity they need, with the rest of the asset value being covered by other developments. A portion of the total asset value will also be socialised (shared amongst the DNO customers).

- **Low development area:** In an area where there is no evidence of significant additional development, as judged by the DNO, the cost of the additional assets is payable by the developer in the first instance. Any additional connections that do materialise may pay a ‘second comer’ charge to the first developer to offset costs, but there is no guarantee for the first developer that this will occur. In some cases, there may be an opportunity for developers to seek out other developers active in the area, allowing them to share costs and unlock development potential within an area. Alternatively, innovative approaches may be adopted by the developer or group of developers to reduce connection charges, for example by managing onsite generation.

The social housing case study is based on a high development area. This means that from the developer perspective, the cost to establish electricity network connection for the electric heating options is reduced to approximately £400k to £650k.

Figure 8-3 shows the energy infrastructure costs apportioned to the developer for the social housing development modelled case study.

Figure 8-3: Energy infrastructure costs for the social housing development modelled case study, showing the costs apportioned to the developer if in a high development area.

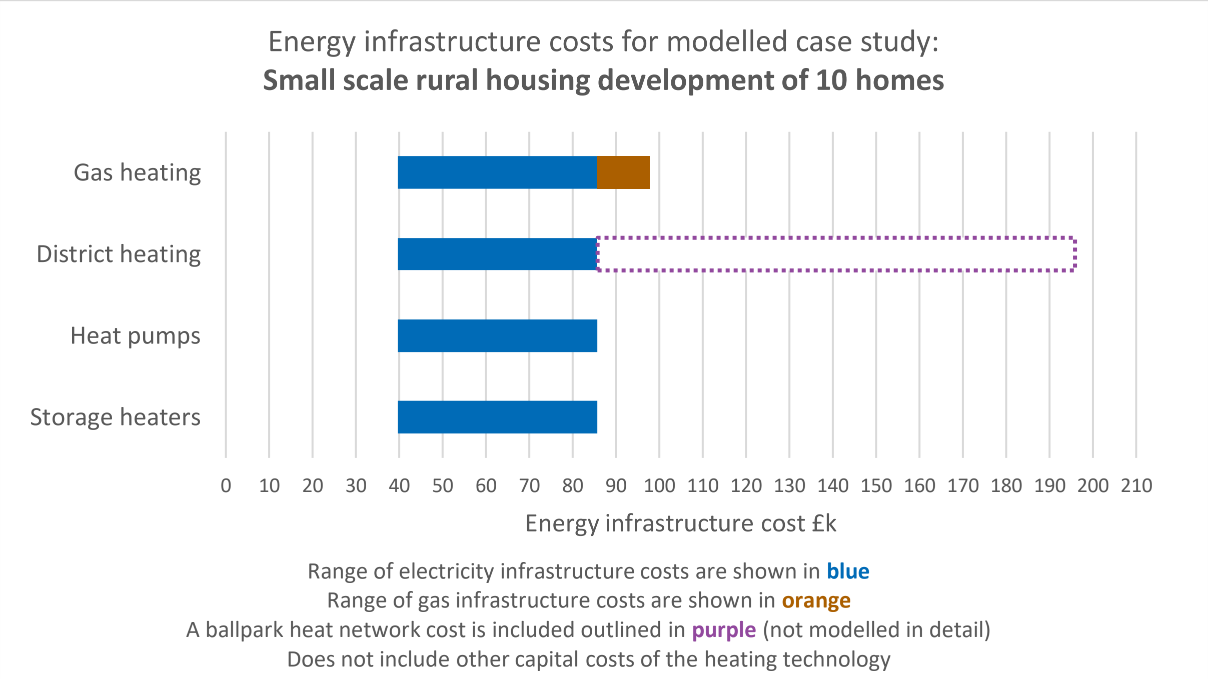


Small Scale Rural Development of 10 homes: The results of the case study modelling for the small scale rural housing development case study is shown in Figure 8-4. This case study is located in a rural location, where there is a little distance between the site and the point of connection. There is often limited capacity in rural networks, but as this is a small development, capacity is available for the connection.

As with the other case studies, the selection of heating technology has an impact on the ADMD of the case study development. The ADMD of the development using gas heating is 31kVA, while selecting storage heaters increases this to 77kVA, and heat pumps results in an ADMD of 80kVA. The technology with the greatest impact on ADMD for the development in this case is heat pumps. This is because, while they are significantly more efficient than storage heaters, the flexibility assumptions for them reduce with a small development. However, it should be noted that the overall energy consumption of the heat pump-based heating system will be significantly less than storage heaters, which is likely to lead to reduced bills depending on tariff options.

However, this variation in demand is not enough to impact the requirements on the electricity infrastructure. In all cases, it is assumed that the development is connected to the nearest high voltage substation over an overhead line, and a pole mounted transformer (lower cost solution than a substation, appropriate for smaller connections and rural locations) is installed onsite to support the development. A pole mounted transformer can be capable of supporting up to 350kVA, which can comfortably support the development.

Figure 8-4: Energy infrastructure costs for the small scale rural housing development modelled case study



Impact of EV charging infrastructure: As with the installation of electric heating technologies, the impact of adding EV charging to the case study housing developments is to increase the maximum demand (ADMD) that the electricity network infrastructure will need to be designed to accommodate.

The inclusion of vehicle charging infrastructure in the private housing development of 300 homes impacts the required electricity network infrastructure required to connect, and therefore the cost of establishing the electricity infrastructure. Figure 8-5 shows the electricity infrastructure costs for different heating technology and EV charging point assumptions.

In every heating technology case, including EV charging across the development increases the electricity infrastructure costs. In some cases (i.e. heat pumps and storage heaters), the increase in load associated with smart charging does not result in an increase in costs over no charging at all, suggesting that there are cases where smart charging can be used to reduce the impact of EV charging demands on the cost of infrastructure. However, this is not consistent for all cases.

Figure 8-5: The electricity infrastructure costs for the private development example case study with different heating technology and electric vehicle charging point assumptions (darker blue = higher costs).

	No electric vehicle	With electric vehicle chargers	With electric vehicle smart chargers
Gas heating	£262k to £586k	£326k to £763k	£269k to £607k
Heat pumps	£326k to £763k	£381k to £913k	£326k to £763k
Storage heaters	£381k to £913k	£436k to £1063k	£381k to £913k
District heating	£269k to £607k	£326k to £763k	£326k to £763k

In the social housing development, the addition of EV charging to each property means that even if the development was to use gas heating, the maximum demand would be above the 100kVA for which there is capacity, and a high voltage substation would still be needed. This is the case for standard charging infrastructure (the ADMD of the case study development with gas heating and standard vehicle charging is 288kVA), and smart charging (where the ADMD is reduced to 183kVA).

Where storage heating and vehicle charging is installed, the maximum demand is 506kVA (401kVA with smart charging), which represents the highest maximum demand technology choice. This case will lead to slightly increased costs due to the requirements of a larger substation.

Figure 8-6 shows the electricity infrastructure costs for the social housing development example case study with different heating technology and electric vehicle charging point assumptions.

Figure 8-6: The electricity infrastructure costs for the social housing development example case study with different heating technology and electric vehicle charging point assumptions (darker blue = higher costs).

	No electric vehicle	With electric vehicle chargers	With electric vehicle smart chargers
Gas heating	£49k to £105k	£4,167k to £6376k	£4,167k to £6376k
Heat pumps	£4,167k to £6376k	£4,167k to £6376k	£4,167k to £6376k
Storage heaters	£4,167k to £6376k	£4,237k to £6536k	£4,167k to £6376k
District heating	£4,167k to £6376k	£4,167k to £6376k	£4,167k to £6376k

For the small scale development, where the heating technology is storage heaters or heat pumps, the additional of EV charging (standard or smart) means that a larger transformer is required, increasing the infrastructure costs. This is also the case for standard EV charging with district heating, though selecting smart EV charging means that the additional cost is avoided.

Figure 8-7 shows the electricity infrastructure costs for the small scale rural development example case study with different heating technology and electric vehicle charging point assumptions.

Figure 8-7: The electricity infrastructure costs for the small scale rural development example case study with different heating technology and electric vehicle charging point assumptions (darker blue = higher costs).

	No electric vehicle	With electric vehicle chargers	With electric vehicle smart chargers
Gas heating	£40k to £86k	£40k to £86k	£40k to £86k
Heat pumps	£40k to £86k	£44k to £92k	£44k to £92k
Storage heaters	£40k to £86k	£44k to £92k	£44k to £92k
District heating	£40k to £86k	£44k to £92k	£40k to £86k

A2.3 Development Examples

The project also identified real development examples that provide context and insight into the project.

A2.3.1 Maiden Hill Development

Maiden Hill, located south of Glasgow, is a development project where they are exploring the use of smart energy management in order to avoid considerable electricity network costs. The development is currently underway involving 3 developers (including CALA Homes, who provided information into the project), IDNO (Energy Assets), DNO (SPEN) and 2 innovation partners (including E.ON, who are providing smart technology).

The initial design of this development included only modest low carbon technologies covering approximately 10% of the homes, and the connection quote from the DNO required no major infrastructure. However, when the site was re-designed to include low carbon technologies in 30% of the planned properties, the DNO assessment and design process revealed a new high voltage substation would be required alongside complex high voltage cabling, costing approximately £7.5m.

In response, the developers, the DNO, the IDNO and technology providers are investigating using energy management technologies to manage the load to within the existing site capacity by maximising the use of electricity generated by solar panels within the development, and managing flexible loads such as hybrid heat pumps and EV charging infrastructure to avoid drawing power at peak times. The technology provider is providing the appliances and the energy management system, which will then be managed by the IDNO.

To date, it is intended that the development will include the installation of the intended low carbon technologies, and the energy management approach will be used to avoid the additional connection costs. In order to make this possible, the DNO needs to be confident that the technology will reliably manage the generation and load on the development site within the boundaries of the connection agreement. If this is not successfully maintained, the wider DNO network may be impacted and the operation may be outside of the statutory limits that all DNOs must adhere to. For this reason, the DNO must be fully on board with the project and work closely with the technology provider.

A2.3.2 Dunfermline congested network

Dunfermline is a high development area, with developments being built and connected frequently. The available capacity within the existing network has been used up; the most recently permitted development was carefully sized at 63 homes, in collaboration between the developer and the DNO (SPEN) to meet but not exceed the available capacity.

Through discussion with SPEN, it is understood that any additional developments will require reinforcements of approximately £5m to £7m. As Dunfermline is a high development area, this cost will not be chargeable entirely to the development that triggers its installation. The developer will be charged at £250k per MVA that they connect to the network. This charge will be payable by all additional connections until half of the infrastructure costs are covered. The reminder of the costs will be socialised through electricity customer bills.

Note – the modelled case study of the social housing development uses assumptions based on the Dunfermline network. This takes the case before the latest development was quoted.

A2.3.3 Insight provided on other real case studies

Several additional real case study examples were discussed by stakeholders, and in many cases, data and information was provided to bring context and insight to the project. The project for which the most complete data was available included:

- **CALA Homes case studies:** CALA Homes is exploring the additional costs and implications of decarbonised heating options through three case study projects; Craibstone, Ravelrig and Jelly Hill. The timing of this work is such that the major findings are expected after the finalisation of this report, but initial insight has been shared with and taken account of by this project.
- **GTC case studies:** The cost quotation and associated diagrams were shared for two case study projects. This included gas and electricity infrastructure costs for a project of 272 homes, all heated by gas, and a second project of 536 homes, 30 of which were gas heated, and the others had heat pump heating systems.
- **SSEN charging point connection:** SSEN provided an example connection quotation, including detailed itemisation of infrastructure and other costs associated with the installation. This provided valuable insight into the formation of these quotes and what can be included.
- **West Lothian Council development with limited network capacity:** West Lothian Council identified a case study project at Mossend in West Calder which is a site for 69 homes, where there is insufficient capacity at the substation to use air source heat pumps. Releasing the required capacity would require a new substation to be built, which is too costly for the Council to justify. This issue may also impact on the installation of electric charging points for cars.

A3 Zero emission heating options

A3.1 Resistance heating

Resistance heaters create heat by running an electric current through a resistor. The resistor has a low efficiency (compared to other forms of electric heating) and proportionally converts one kWh of electricity to one kWh of heat. This means that fulfilling a significant heating demand requires an equally significant power load.

Resistance heating has low capital costs due to their cheap parts and simple installation. The caveat is that the rate of electricity conversion causes a high operating cost. It is for this reason that resistance heaters are best suited for properties that have low space heating demand by either having a small floor area and/or having a high-performance thermal envelope. In such circumstances, the domestic hot water becomes the driving heat requirement.

There are various ways the technology is applied in order to provide space heating or hot water.

A3.1.1 Convection heaters

Much like traditional home radiators, convection heaters use heating elements to heat air within a property. Heat is generated the moment the heating elements have reached temperature. Hot air is less dense than cool air and so rises due to its buoyancy. The hot air is continuously replaced with colder air yet to be heated. They can come equipped with fans to speed up airflow. Whilst they can be wall mounted, they are often sold as free-standing units to supplement inadequate home heating.

The timing of electricity load is determined by the heat demand. Use of multiple heaters simultaneously can trip a domestic property ring circuit by exceeding the maximum designed electrical loading of 23kW.

A3.1.2 Immersion heaters

Immersion heaters use their heating elements to heat water in a hot water cylinder. They often come as standard with hot water cylinders to be used as a primary source of water heating or to provide a back-up to primary heat sources such as conventional boilers and heat pumps.

In the case of air source heat pumps, immersion heaters are a necessary companion technology to provide pasteurisation cycles at temperatures unreachable by heat pumps.

Water tanks are well insulated and act as a thermal store, retaining heat until its future use. A benefit of this is that demand can be managed so that heating is completed overnight when grid demand is low and consequently multi-tariff electricity prices are too. Immersion heaters typically demand a minimum of 3kW by design and therefore have a significant impact on a property’s load at the time of use.

A3.1.3 In-line heaters

In-line heaters can provide space heating and/or hot water by heating water. Rather than heating water in a cylinder, in-line heaters will heat water in transit. They are integrated into the water flow pipeline and use an electric element to heat water en-route to its point of use.

They can be used with or without hot water tanks but are more often used when there are space constraints, meaning there is no tank.

A3.1.4 Night storage heaters

Night storage heaters are convection heaters that have an in-built thermal store. They contain thermal bricks that are made of high-density materials. The thermal bricks are heated over night when grid demand is low and consequently multi-tariff electricity prices are too. The thermal bricks radiate their internally stored energy throughout the day, preventing or reducing the need for the unit to provide convection heating during the day when electricity prices are higher.

A3.2 Heat pumps

Heat pumps operate by taking advantage of the vapour compression refrigeration cycle. This technology has been used commercially in refrigerators and air-conditioning units since the 1850s and has been repurposed in more modern times to provide heating.

A heat pump passes low pressure, low-temperature refrigerant fluid through a heat exchanger that draws heat from an external heat source that evaporates the refrigerant. The refrigerant gas is then passed through an electrically driven compressor to compress it, increasing its temperature and pressure. The heated gas is then passed through another heat exchanger where heat is transferred to a transfer medium to be emitted within the property or hot water tank. The transfer of heat also causes the refrigerant gas to cool and condense back into a liquid. The warm liquid is then passed through an expander to lower the pressure which causes a drop in liquid temperature. The low pressure, low-temperature liquid is then ready to begin the cycle once again [9].

The unit's compressor is the key source of electricity demand. The higher the temperature difference between the heat source and the target heat, the harder the compressor will work and the more electricity it will require. Therefore, the temperature of the heat source, and the temperature required at the end use have an impact on system efficiency. The end use could be for hot water which commonly requires the maximum of the heat pump to reach temperatures of 55 °C or for space heating which is dependent on the heat requirement of the emitters to meet the properties target room temperature. Heat emitters are discussed further in A3.2.2.

A3.2.1 Heat sources

There are a variety of sources that heat pumps can be configured to extract heat from. The different sources range in temperature and therefore are a key consideration for system operation and efficiency. They are described below:

- Air source – These heat pumps extract heat from the outdoor air. They are relatively cheap and straightforward to install when compared to other heat sources described below and are also the most commercially mature. A disadvantage is that air temperature can vary significantly month to month and so the system will have to work harder in the winter months to raise the temperature of the refrigerant to what is required, therefore, the unit is often least efficient when it is needed most. In circumstances where outdoor temperatures risk freezing the refrigerant, the heat pump may enact defrost cycles to prevent it, also reducing system efficiency.

- Ground source – These are configured to collect heat from the ground through heat exchangers in horizontal trenches or vertical boreholes. Boreholes take advantage of ground heat that increases in temperature with depth. For horizontal collectors, the area that heat is extracted from is replenished by solar gain or rainfall. For both systems, the general consistency of temperature provides a reasonably constant efficiency of the heat pump cycle no matter the weather conditions.
- Water source – Water source heat pumps perform similarly to ground source heat pumps due to the consistency of the temperature. The circumstances where heat pumps have access to water often mean that water cooled by the compression cycle is quickly replaced by warm water through convection or from natural flows such as those of a river.

A3.2.2 Transfer mediums

Heat pumps can provide heat to properties through two different transfer mediums. Heating through air is most common in commercial buildings where cooling may also be required. Ducting systems with fans circulate the warmed air around the building and distribute it where it is needed.

Water based systems are more common in domestic properties that typically only require heating. The heated water is transferred through piping around the property and delivered to radiators or underfloor heating systems to emit the heat. The more surface area the emitter has, the lower the temperature that is required to emit an equivalent amount of energy. A lower target temperature for a heat pump requires less work from the compressor, therefore increasing system efficiency. As underfloor heating systems have a large surface area, they are typically the most efficient option for space heating. There is a significant opportunity for low cost integration during the building of new developments.

A3.2.3 Hybrid heat pumps

Hybrid heat pumps combine heat pumps with conventional boilers. The heat pump component may be sized so that it only meets the requirements for the majority of the property's heating demand and leaves the conventional boiler to facilitate the remainder of demand or the hot water tank specifically. Most hybrid heat pumps combust fossil fuels in the conventional boiler but as the energy transition gains momentum their fuels may be replaced with low carbon alternatives such as biofuels or hydrogen.

A3.3 District heating

District heating systems take advantage of economies of scale to efficiently deliver heat to properties and decrease the dependency of properties on individual technologies. Heat networks can range in size from a shared system amongst a few properties to multi-technology systems interconnected between entire cities.

A heat network delivers heat through water transmitted through insulated pipes. Individual dwellings will tap into the heat network and extract the heat that they require without having to generate any themselves. In cities where dwellings are likely to have space constraints this is particularly useful as floorspace or storage space is relieved that would otherwise house a hot water cylinder or gas boiler. The amount of heat consumed within a property is monitored and invoiced much like any other utility bill.

The source of heat ranges depending on the system but can include waste heat from industrial processes, solar heating, heat pumps and conventional combustion boilers.

A3.3.1 Thermal stores

Thermal stores can be integrated with any technology but are more commonly associated with district heating systems where heat generation is not driven by heat demand. Thermal stores are well insulated storage units that will offset the heat supply until it is demanded. In the case of electrified heating, thermal stores can also be advantageous for generating heat when demand on the grid is low and subsequently electricity prices are cheap, thereby reducing the operating cost of the system.

A3.4 Emerging technologies

There are novel heating technologies that are not included in the project scope due to their commercial immaturity. This section provides a brief overview of those technologies that are worth consideration in the medium to long term future.

A3.4.1 Phase change materials for thermal storage

Phase change materials are often denoted as “heat batteries”. The heat loss is low over time and release can be triggered whenever the owner requires it. They are particularly well suited for small apartments due to their high volumetric latent heat storage capacity that allows them to take up a small space footprint.

A3.4.1.1 Sunamp

Sunamp is a company that is providing a phase change material solution in the present future. They use primarily solar panel generated electricity to transfer heat into a phase change material that integrates with existing heating systems. Their size is tailored to the needs of the system and can be expanded if needed [29].

A3.4.2 Heat recovery ventilation

Highly efficient building envelopes, such as those that conform to “Passivhaus” standards may use heat recovery in their ventilation systems. The system passes extracted air through a heat exchanger to preheat air being drawn into the building. This decreases heat loss during air ventilation to further increase energy efficiency of a property. Heat recovery ventilation units may become a common solution among property developments if building energy efficiency regulations reach a high enough standard.

A3.4.3 Infrared heating

An infrared heater transfers energy to an object with a lower temperature through electromagnetic radiation. Depending on the temperature of the emitting body, the wavelength of the peak of the infrared radiation ranges from 780 nm to 1 mm. The method of transmission of energy allows for a wider spread of heat than can be achieved with convection heating and provides longer term warming of objects within the room.

A3.4.4 Transcritical heat pumps

Transcritical heat pumps use carbon dioxide as the refrigerant gas. They have the same basic configuration as any heat pump. However, due to the different properties of CO2, a much larger temperature difference across the heat distribution system is required. This means that transcritical heat pumps require a low return temperature (usually below 30 °C) but can supply high flow temperatures (over 80 °C). They may be suitable for heating hot water storage tanks or high temperature requirements in industry.

A4 Innovative project summaries

A4.1 Spatial Analysis of Future Electric Heat Demand (SAFEHD)

This project aims to develop and apply methods to explore optimal decarbonisation pathways to determine likely future heating technology mixes against a backdrop of policy, cost and demand uncertainties [11]. The first package is split into three phases:

1. A geospatial analysis that will generate high spatial resolution heat energy demand estimates based on actual energy consumption data and investigate how these heat demands relate to type of heating system, dwelling characteristics and social demographics. It will also characterise households by their behaviour and attitudes towards alternative heating technology uptake.
2. Development of the SAFE-HD agent-based model and explore the spatial distributions of future electric heat demand under uncertainty.
3. To conduct a network impact assessment with the aim of identifying least regret network investment options required. As well as to provide recommendations as to how the tools and methods developed for the SAFE-HD project can be used by all DNOs.

The second package of the project will extrapolate individual low carbon technologies effect on ADMD and assess the impact of heat pumps and electric water heating in off gas grid areas.

A4.2 Heat street

Heat Street is a year-long research project that aims to develop an approach to forecasting adoption of energy efficiency measures and low carbon heating solutions [12]. The project will also carry out a zoning assessment to gain insight on what areas may be particularly well-suited to electrifying their heating needs. Criteria such as regulatory considerations, geospatial, fairness, practicality and speed will be included in the assessment. The objectives of the project are to:

- Collate existing information in a way which is useful for energy networks to progress their thinking on the decarbonisation of heat;
- Develop understanding of trends and dependencies for energy efficiency and low carbon heating implementation; and
- Develop and conduct a zoning assessment with input from stakeholders to understand how to identify where customers will benefit most from installing electric heating solutions.

A4.3 Regional Energy System Optimisation Planning (RESOP)

SSEN and Dundee City Council partnered to develop a whole system planning tool that incorporates the net-zero objectives of local councils whilst assessing the impact of those plans and the technologies they use on the local electricity network [13]. It was built after a decision from SSE's Greenprint to empower the energy transition through the deployment of Local Area Energy Plans (LAEPs). The model that is developed over the course of the project will seek to optimise outputs for local stakeholders, who will be trained in use of the model to help inform their decision making.

A4.4 Electrification of Heat Demonstration Projects

This project aimed to demonstrate the feasibility of large-scale roll-out of heat pumps in GB by installing innovative heat pumps in a representative range of 750 homes, together with new products and services designed to overcome some of the barriers to deployment [14]. The programme is supporting three delivery contractors to conduct the trials and has the following objectives:

- Develop, test and evaluate innovative products and services that increase the appeal of heat pumps and identify optimal solutions for a wide range of homes;
- Demonstrate that heat pumps, including gas-electric hybrids, can deliver high consumer satisfaction across a wide range of consumers in GB;
- Demonstrate the practical and technical feasibility of heat pumps, including gas-electric hybrids, across GB's diverse housing stock; and
- Capture learning from the project to help improve awareness across the heating supply chain, raise acceptance and support wider deployment of heat pumps in GB.

A4.5 Flexible Residential Energy Efficiency Demand Optimisation and Management (Freedom)

Western Power Distribution ran the Freedom project for 27 months to investigate the feasibility of the use of hybrid heat pumps on their network [15]. The research objective is to better understand how hybrid heating systems can be:

- Affordable through using advanced algorithms to unlock value from energy markets;
- Trustworthy by building consumer trust in new technology whilst providing the same level of comfort in people's homes; and
- Developing appropriate user interfaces and information systems to help drive adoption.

75 smart heating hybrid pilot installations were rolled out amongst trial properties before beginning a year-long monitoring and experimentation phase to iteratively refine the heating and load management processes.

As a result of the work delivered in the Freedom project, hybrid heating systems demonstrated that they are a complementary solution across the various futures of heat pathways, providing the opportunity for partial electrification combined with hydrogen in major cities and other decarbonised gas elsewhere.

A4.6 Cold Start

UK Power Networks are aware that the electrification of transport and heat will have large impacts on the electricity grid. Reinforcing the grid to meet the needs of the demand will be to provide technical challenges, one of which will be the consumer behaviours during restoration of power after an extended outage. With widespread adoption of electric heating and vehicles, the restoration of power after an extended period will have the added challenge of needing to heat buildings and charge EVs.

Using the Energy System Catapult's EnergyPath Operations tool, the project will build a network simulation model of an area of the electricity network to assess how energy demand responds following a cold start [16]. The model will inform decisions and policy around cold starts and what future studies on technical applications and/or commercial solutions would assist in keeping power supplies reliable.

A4.7 4D Heat

This project explored whether controlling electrified residential heating in Scotland can be used to reduce the curtailment of renewable generation, without adversely impacting the distribution network [17].

The work focussed on Skye, an off-gas grid area in northern Scotland with high proportions of electrified residential heating, and homes with potential to switch to electric heating. It's estimated there are currently around 380,000 such homes in Scotland which could move to a range of electric heating solutions, from storage heaters to air or ground source heat pumps, doing so would take advantage of surplus wind power. The projects objectives were to:

- Analyse how well DNO and ESO constraints match with available flexibility from electric heating
- Conduct cost benefit analysis (CBA) to identify if this is cost effective, and how it scales up to all off-gas grids in Scotland.
- Further excel-based techno-economic modelling will aim to calculate the cost benefit analysis of using the flexibility of domestic heating compared to traditional solutions to manage constraints (curtailing renewable generation and network reinforcement).

One of the key findings were that UK consumers could see financial benefits in the region of £26 million per year if their homes were heated with wind energy. The analysis found that 17% of curtailed wind could be absorbed by electric heating systems in 2020 and 9% in 2030. By 2030, some households could be saving 18% on their annual energy bill. It suggested as much as 540GWh of wind power could be absorbed by domestic heating across off-gas grid Scotland in 2030, saving £24 million per year in wind constraint payments.

A4.8 Northern Isles New Energy Solutions (NINES)

The NINES project in Shetland introduced methods to manage the distribution network more effectively [18]. The project is using large and small scale energy storage solutions combined with an active network management system to create a smart grid in Shetland. The project is providing more comfortable and affordable heating through installation of smart electric heating systems. Key aspects of the project include:

- A 1MW battery to manage fluctuations in supply and demand
- Replacing storage and water heaters in 1,000 homes with modern smart storage heaters
- Adding an electric boiler to a district heating system associated with a local wind farm
- Deploying technology that will allow small scale renewable generators to connect to the network

A4.9 Electrical Heat Pathways: Looking Beyond Heat Pumps

In the ongoing debate about future energy policy, there has been a presumption of any electrified heat pathway being based around the use of heat pumps. Despite being less efficient than heat pumps storage heaters can be the only option for vulnerable people or technically unsuitable properties. They are more commonly arriving to market with smart control systems that could be used by distribution network system operators as demand side response resources. Installers should have the required skills to deal with complex arrangements that allow the distribution network to determine the timing schedules for storage heaters in constrained areas that would otherwise need costly reinforcement. These signals are currently sent over what is known as the Radio-Teleswitch System (RTS) using the long wave radio infrastructure provided by the BBC. However, this is shortly due to be de-commissioned.

The report found that Ofgem and BEIS need to give proper consideration for the place of storage heaters in heat decarbonisation [19]. Policy should not inadvertently act as a barrier. Customers should be provided independent customer advice and support to make appropriate choices on low carbon heating solutions. SSEN will begin to develop commercial arrangements to properly reward the provision of flexibility and diversity provided by storage heaters through the RTS arrangements.

A4.10 Copenhagen district heating and cooling system

In Denmark in the city of Copenhagen, waste is burned to generate heat and that is used city wide to provide heat for 98% of homes in the city cleanly and cheaply [20]. Other methods of heat generation are:

- Waste heat released from power stations and industrial processes;
- Solar heating;
- Large scale heat pumps;
- bio-gasification of organic waste; and
- geothermal energy.

The heat is transported via a water medium through a network of pipes across the city. This helps to save 200,000 tonnes of oil every year and thereby reduces 665,000 tonnes of CO2 released to the air.

Copenhagen aims to become the world's first CO2 neutral capital by 2025. District heating is the biggest contribution to reduce CO2 in the municipality. Since 2010, district cooling also contributes to reduce CO2 which potentially reduces the city's atmosphere of 80,000 tons of CO2. District cooling is done by circulating the seawater to the major companies in Copenhagen.

Denmark's heating and cooling industry is attracting global interest, as countries seek best practice in design and installation.

A4.11 Queens Quay district heating scheme

This district heating scheme project is based near Glasgow in Scotland and will provide heat to 1,200 homes as well as a health centre, a care home and businesses. It will use two 2.5MW water source heat pumps to extract heat from the River Clyde and transport it to locations of demand [10].

When the heat pumps generate excess heat, it will be stored in the thermal store and then released when needed. The two water source heat pumps will meet the majority of the networks design providing heat to the network at 75ºC flow and 45ºC return. During summer, one heat pump will be kept offline while the other is still running. Gas boilers with a combined capacity of 15 MW installed in the energy centre are used for a small percentage of the time to meet peak demand or as a backup option. This system will not produce carbon emissions or nitrogen dioxide emissions.

The river's temperatures throughout the year generally ranges from between 6-12ºC.

A4.12 ENGIE harmony project with Enfield Council

This project focussed on ground source heat pumps providing heat to 400 flats in eight blocks across two estates in the London Borough of Enfield [21]. The flats are retrofitted with Kensa Shoebox heat pumps that extract heat from pipes that are distributed underground across 52 boreholes. Along with being climate friendly, the system is expected to save residents up to a third on their heating bills and the boreholes have a lifetime of 100 years.

A4.13 Other innovative approaches

Other innovative approaches are as follows with reference to Appendix A2:

- The Maiden Hill site near Glasgow, where innovative tools were used to reduce the impact that zero emission heating in homes had on the connection costs.
- CALA Homes are exploring the additional costs and implications of decarbonised heating options through three case study projects.
- SPEN are producing an ADMD calculator, which can estimate the impact that different types of heating technologies have on their ADMD.

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