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Geospatial modelling of heat pump uptake on electricity network infrastructure

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Domestic heat pumps will play a significant role in decarbonising Scottish homes and achieving Scotland's 2030 emissions targets under most future scenarios. Heat pumps can provide an energy-efficient solution for the heating and cooling of buildings and as a result, are considered one of the most effective technologies available to decarbonise buildings. Although efficient and effective in appropriately insulated homes, heat pumps can significantly increase the electricity demand of a house. The peak demand of a house can increase by a factor of three or more for a house switching from a gas boiler to a heat pump which has the potential to challenge existing network capacity.

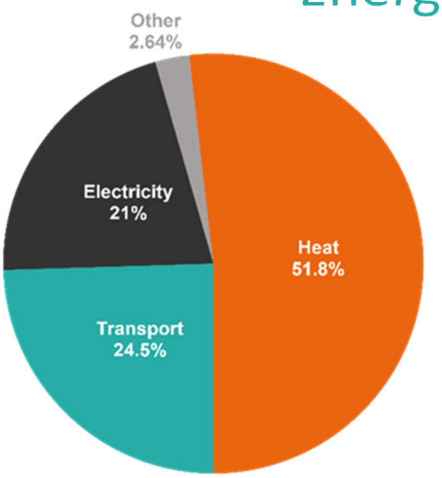
Across different locations in Scotland, there are significant variations in terrain, housing stock, demographic and climatic conditions amongst other ecological factors. As such, there is substantial variation in the available network capacity in different regions, as network design and infrastructure requirements are tailored to meet inherent demand requirements which means that heat pump uptake will vary at different rates and volumes across Scotland. Therefore, a range of policy, economic and technical factors are expected to influence and drive uptake rates in different areas.

In many areas, work will be required to upgrade the network to accommodate the additional electricity demand associated with heat pump deployment. This work will take time, money and potentially cause disruption to consumers, creating an additional barrier to uptake. Understanding these factors and how they differ spatially across Scotland will be key for local authorities (LAs) to effectively produce Local Heat and

Energy Efficiency Strategies (LHEES) and for distribution network operators (DNOs) as they plan and deliver on their investment decisions.

This presentation outlines a methodology for assessing the geospatial impacts of heat pump uptake on electricity network infrastructure across Scotland under several future scenarios.

Energy consumption



Final energy consumption by sector in Scotland in 2020

- Heat requires extensive decarbonisation to meet emissions reductions targets
- Estimate between 517,000-717,000 domestic properties need to install heat pumps by 2030 to meet climate targets

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- Heat, both in domestic buildings and industry, made up 51.8% (80.14 TWh) of final energy use in Scotland in 2020 and is therefore an area that requires extensive decarbonisation to meet emissions reductions targets.
- There are several technological options for achieving zero emissions heating in buildings, each with relative merits and limitations. Any likely future will contain some proportion of each, but at present, the volume and location remains uncertain. The four key technological solutions are:
    - replacing natural gas with hydrogen created from low carbon electricity;
    - using direct electric heating or heat pumps;
    - burning sustainable biomass; and
    - use of heat networks supplied by any of the three heat sources above.
- There are two types of low regret options that could be prioritised for retrofit:
    - Installing heat pumps in houses currently burning heating oil or LPG that are not connected to the gas grid (around 170,000 in Scotland). LPG and heating oil emit far more CO_2e for equivalent heat supply than natural gas, incentivising targeting these properties first to meet emissions reductions targets.

  - Adopting heat networks in areas with a high density of heat demand. These networks offer a cost-effective solution in locations with concentrated heat demand such as blocks of flats or offices and can make use of heat obtained from rivers, waste industrial heat and even mine water geothermal energy.

- The total emissions budget for buildings in 2030 is 2.6 MtCO2e, compared to 8 MtCO2e in 2020. **How close to the 2030 targets are these low regrets options likely to get us?**

- The pathway set out by the Scottish Government to achieve the heating element of these reductions is summarised as follows:

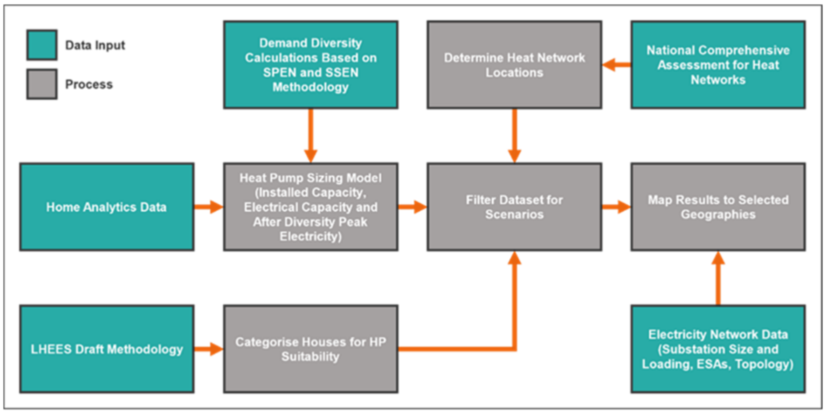
  - Almost all domestic properties that are unconnected to the gas grid and will be converted to zero emissions heating (170,000).
  - In addition to all high emissions off-gas properties, at least 1 million additional domestic properties currently connected to the gas grid and 23% non-domestic properties (50,000) will need to be converted to zero emissions heating by 2030.
  - 6 terawatt hours (TWh) of heat will be supplied by heat networks annually by 2030 (equivalent to 400,000 - 600,000 average houses depending on size) across both domestic and non-domestic heat demand. This is a statutory requirement of the recently passed Heat Network Act.
  - From 2024, all new build properties will use zero emissions heating.

- To obtain an estimate for the number of heat pumps that are required, heat network suitable properties can be removed from the total number of properties in Scotland. This results in an estimate of between 517,000-717,000 domestic properties that would need to install heat pumps by 2030 to meet climate targets (this may reduce subject to hydrogen evolution).

- There are significant costs to install a heat pump: the capital costs of the unit, the required upgrades to building fabric and heat emitters to allow for lower operational temperatures. Additionally, due to the increase in electrical demand, the electrical network may require upgrading. To connect a heat pump there needs to be sufficient capacity on all assets in the local electricity distribution network. If an asset lacks capacity it does not prevent installation, but rather requires network reinforcement – resulting in possible costs to the connecting customer(s).

- DNOs use the After Diversity Maximum Demand (ADMD) metric to determine how much network capacity needs to be available for each customer. However, they are typically limited in terms of the actions they can take when upgrading electricity network assets. The current approach only allows for them to install the minimum viable scheme (the smallest possible set of upgrades that can facilitate the change needed). RIIO-ED2 will see a change in the revenue streams for DNOs that will foster an approach to ahead of need investment.

Heat pump impact assessment methodology



High-level overview of the developed methodology

- Comprises a number of discreet elements and draws on several datasets.
- Can be used to provide an assessment of the electricity network impacts of heat decarbonisation in Scotland.

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The methodology comprises a number of discreet elements and draws on several datasets. In combination these can be used to provide an assessment of the electricity network impacts of heat decarbonisation in Scotland.

The methodology adopted in this work takes the following steps:

- LHEES Heat Pump Prioritisation Model: Categorise each property in Scotland according to their suitability for heat pump installation using the Scottish Government's Local Heat and Energy Efficiency Strategy methodology.

- Identify required heat pump size based on rated heat output in kW for each domestic property, using the Home Analytics database of domestic Scottish properties and heat pump sizing model.

- Calculate the additional peak electricity demand in kW resulting from the retrofit of each heat pump using the domestic ADMD tool created by SPEN and SSEN.

- Categorise each property based on its proximity to a heat network zone using outputs from the UK Government's National Comprehensive Assessment for Heat Networks.

- Determine policy-based scenarios for the location of heat pump uptake through a co-design process with policy stakeholders.

- Determine the impact of heat pump uptake on peak demand in kWs at primary substation level for all of Scotland.

After diversity maximum demand calculator

Variables	Options / Ranges	User Input
Number of Customers on Feeder ?	20 to 100	100
How many have EV Chargers ?	0 to Number of Customers	0
How many have EV Chargers AND Heat Pumps ?	0 to Number of Customers	0
How many have Air Source Heat Pumps ?	0 to Number of Customers	0
Average size of ASHP? (kW Heat)	0, 5, 8 or 16	8
How many have Ground Source Heat Pumps ?	0 to Number of Customers	0
Average size of GSHP? (kW Heat)	0, 5, 8 or 16	16
How many have Hybrid Heat Pumps ?	0 to Number of Customers	0
Average size of HyHP? (kW Heat)	0, 5, 8 or 16	5

SP ENERGY NETWORKS

Scottish & Southern Electricity Networks

	kW Output
Average HH ADMD Standard	1.80
Total Feeder ADMD Standard	180.00
Average HH ADMD Cold Load	1.80
Total Feeder ADMD Cold Load	180.00

Example of the SPEN/SSEN distribution ADMD calculator

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LHEES Heat Pump Prioritisation Model

- Each domestic property is categorised into one of three categories, dependent on its suitability for heat pump retrofit. These categories are derived from the developing LHEES methodology.
- **Category 1** contains the highest priority properties, determined by the following criteria:
  - windows are double or triple glazed;
  - the property is not a listed building;
  - walls and loft are insulated where possible; and
  - the property is not connected to the mains gas grid, the primary heating fuel is LPG, Oil or Biomass.
- **Category 2** is a less stringent categorisation of medium priority properties with the following criteria:
  - does need meet the category 1 criteria;
  - is not a listed building;
  - is not in a conservation area; and
  - is not an insulated solid stone or timber-built property.
- **Category 3** consists of all other properties.

- **Heat Pump Sizing Model and ADMD**
  - Firstly, the heat pump sizing model determines the rated heat output in kW for the selected property by considering the floor area, number of floors, building type and number of external walls. It is assumed in all cases that air source heat pumps are used.

  - SPEN and SSEN jointly developed ADMD tool is then used to calculate the peak demand contribution.

Linear heat density

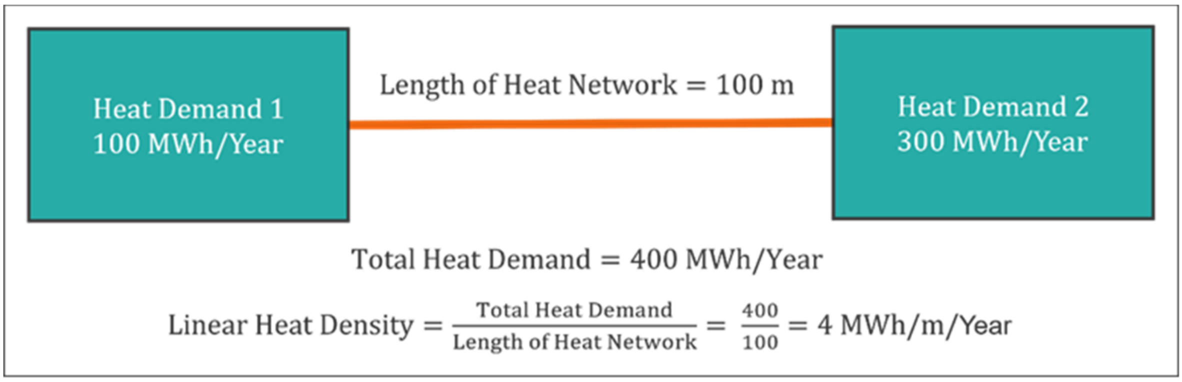

Illustration of linear heat density

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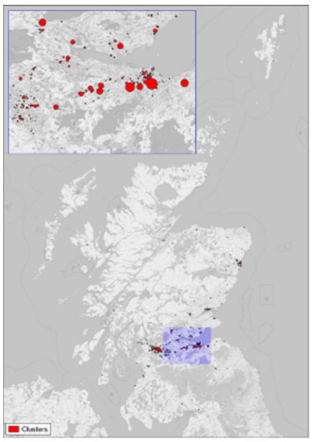
Heat Network Zone Identification and Electricity Network Infrastructure

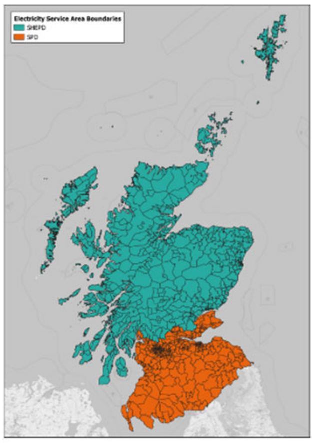
- The methodology used to identify heat network zones utilises linear heat density (LHD) to identify locations with geographically concentrated heat demand and suitable high demand anchor loads.
- SPEN and SSEN provided geospatial boundaries known as Electricity Service Areas (ESAs) for each of their licence areas. These represent geographic areas supplied by individual primary substations.
- The total new electricity demand caused by domestic heat pumps (and heat networks) can be aggregated within each ESA.

See maps on next slide

Clusters and electricity service areas



Clusters from highest LHD scenario from the UK National Comprehensive Assessment for Heat Networks



Electricity Service Areas

Peak electrical demand increase – Scenario 1

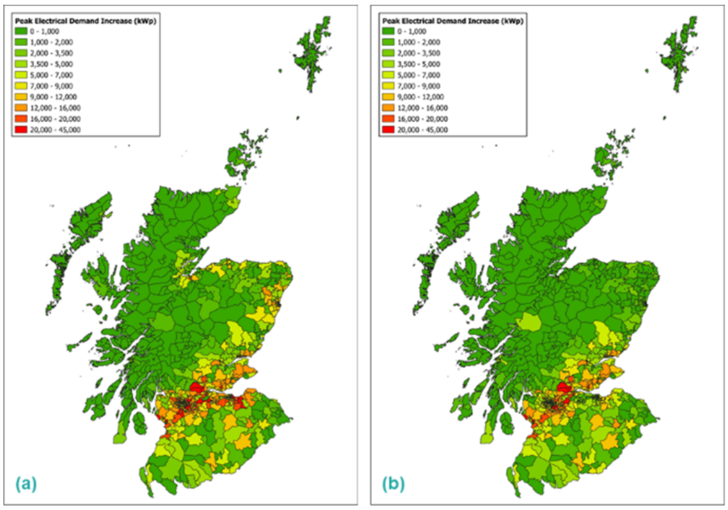


Figure 7
Peak electrical demand increase for Scenario 1 by ESA:
(a) Without heat networks
(b) With heat networks

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- The methodology for assessing the geospatial impacts of heat pumps on electricity network infrastructure is applied through a series of different scenarios supporting comparative analysis.
- Four scenarios are explored in this work and are based on different levels of heat pump uptake.
- Each of these scenarios are explored based on two cases, with and without heat networks i.e., heat demand is solely met by heat pumps or by heat pumps and heat networks:
  - Scenario 1: all Category 1 properties.
  - Scenario 2: all Category 1 and all other off gas properties.
  - Scenario 3: all Category 1 and 2 properties.
  - Scenario 4: all Category 1, 2 and other off gas properties.
- To meaningfully compare the scenarios, the following assessment metrics are considered.
  - Peak electrical demand increase at a primary substation.
  - Available 'headroom' at each primary substation.

- Headroom here refers to the expected amount of unused network capacity available for larger (primary) substations (33kV to 11kV or 6.6kV). This provides an indication of where physical upgrades may be needed in the network now or in the future or where flexibility services could be used/procured to help operate the network more efficiently.

- The results that follow show the peak electrical demand increase (kWp) at each individual primary transformer per ESA for each scenario.

- In the figure on this slide, the impact of heat pump uptake on peak electricity demand is observed across Scotland. In comparison of Figure 7(a) and Figure (b) the impact of heat networks is evident, particularly in the northeast of Scotland as the peak electricity demand increase is reduced for certain ESAs. This suggests that heat pump uptake is likely to have less of an impact in these areas in terms of peak demand increase when heat networks are present.

Peak electrical demand increase – Scenario 2

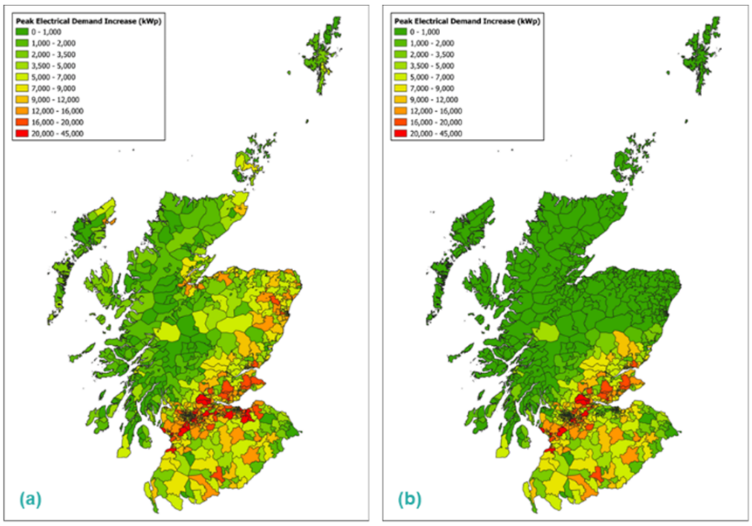

Figure 8
Peak electrical demand increase for Scenario 2 by ESA:
(a) Without heat networks
(b) With heat networks

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- For Scenario 2, Figure 8(a) demonstrates that as heat pump uptake is increased to include all other off gas properties the peak electrical demand increase is more prominent in areas that are typically off-gas.

- In Figure 8(b), as the heat networks are introduced, peak electrical demand increase is again reduced. This emphasises to some extent that heat-networks have the potential to support decarbonisation in rural areas including small towns and villages with suitably large anchor loads.

- In comparison of Figure 7(a) and Figure 8(a) the impact of heat pumps in isolation is significantly increased when all other off-gas properties are included in addition to category 1 properties. This indicates that most off-gas buildings do not meet the building fabric criteria to qualify for category 1.

Peak electrical demand increase – Scenario 3

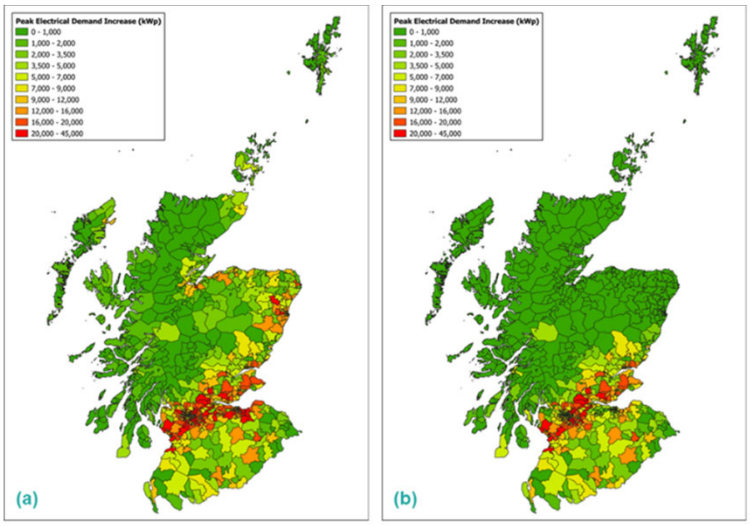

Figure 9
Peak electrical demand increase for Scenario 3 by ESA:
(a) Without heat networks
(b) With heat networks

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- Figure 9 highlights the peak electrical demand increase results for Scenario 3 with and without heat networks. This scenario includes both on- and off-gas networks therefore the impact of heat pumps varies across Scotland and is not directly contained to off-gas areas as with previous scenarios.

Peak electrical demand increase – Scenario 4

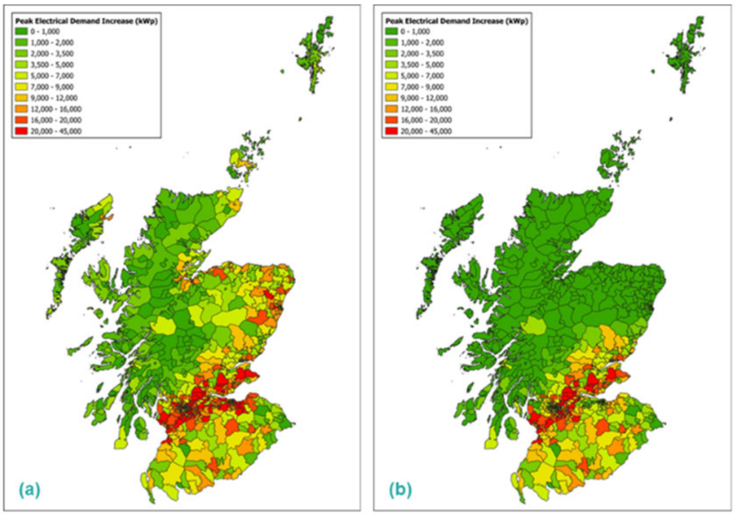

Figure 10
Peak electrical demand increase for Scenario 4 by ESA:
(a) Without heat networks
(b) With heat networks

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- In Figure 10(a), when all properties are considered the full extent heat pumps are expected to have on peak electrical demand increase at a primary transformer level for across Scotland is demonstrated.

- Figure 10(b) then indicates how addition of heat networks is likely to alleviate the scale of this impact in different geographic areas.

Peak electrical demand increase – Aberdeen

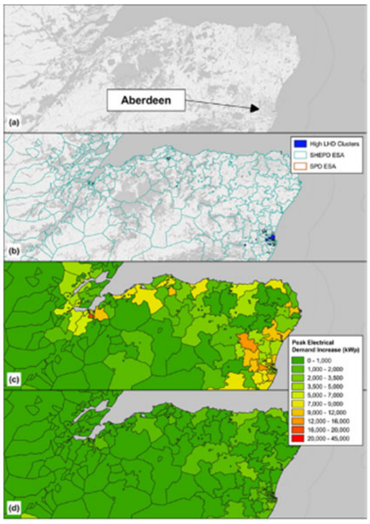

Figure 11
Scenario 1 step by step enhanced:
(a) Map of Scotland
(b) High LHD clusters per ESA
(c) Without heat networks
(d) With heat networks

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- In Figure 11, a step-by-step enhanced comparison is provided which demonstrates the impact heat networks have on the peak demand increase. The reductions in demand increase are typically relative to the size of the modelled clusters.

Peak electrical demand increase – Glasgow

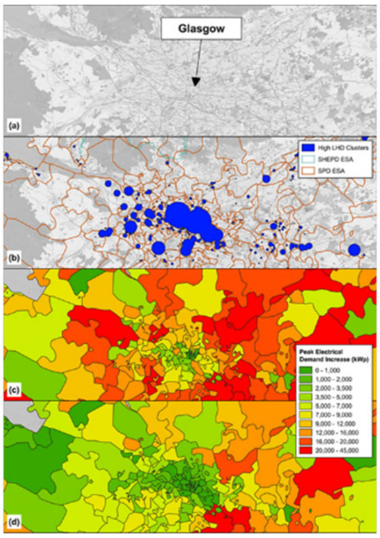

Figure 12
Scenario 1 step by step enhanced:
(a) Map of Scotland
(b) High LHD clusters per ESA
(c) Without heat networks
(d) With heat networks

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- This slide further emphasizes that because the scenarios include both on- and off-gas networks the impact of heat pumps varies across Scotland and is not directly contained to off-gas areas as with previous scenarios.
- Figure 12 shows a step-by-step enhanced comparison is provided for Glasgow.
- Figure 12(b) indicates that Glasgow has a large cluster density and the impact of this is evident in comparison of Figure 12(c) and Figure 12(d) on the city and surrounding areas.
- This highlights how heat networks under the modelled conditions can alleviate the impact of heat pump uptake in areas with a high population density.

Headroom results – Scenario 1

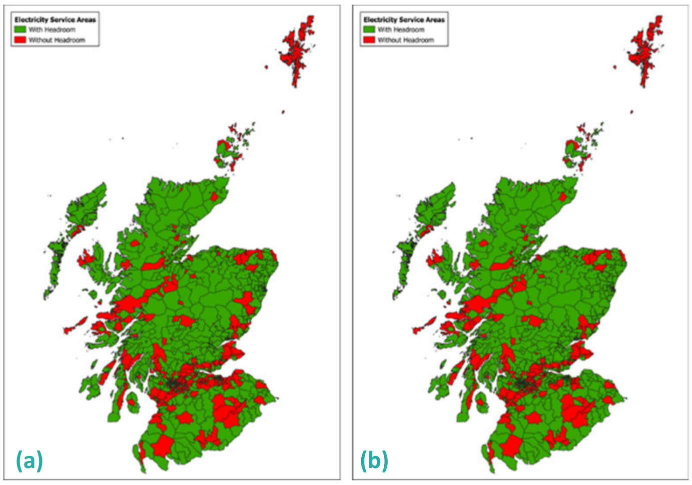

Figure 13
Headroom for Scenario 1 by ESA:
(a) without heat networks
(b) with heat networks

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- The geospatial results that follow show the electricity service areas with and without headroom at each individual primary transformer per ESA for each scenario. This allows for comparison between individual cases for each scenario and cross comparison of cases across differing scenarios.

- For Scenario 1, Figure 13 highlights the primary transformers based on their associated ESA with and without headroom. In comparison of Figure 13(a) and Figure 13(b) the impact introducing heat networks has on headroom is limited in this scenario.

Headroom results – Scenario 2

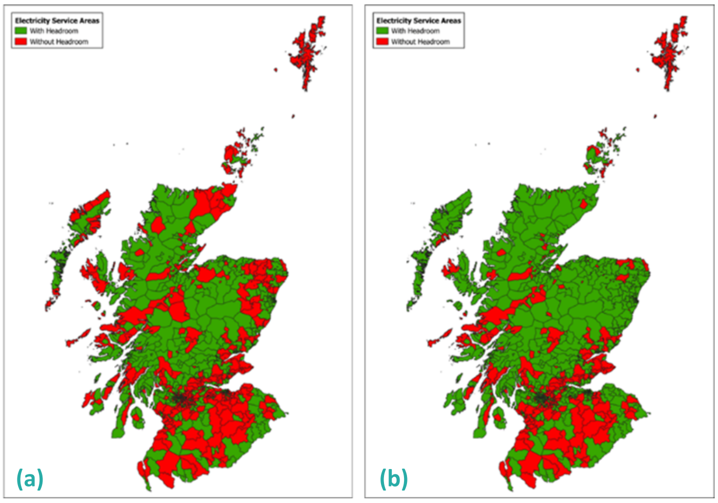

Figure 14
Headroom for Scenario 2 by ESA:
(a) without heat networks
(b) with heat networks

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- In comparison of Figure 13(a) and Figure 14(a) when all other off-gas properties are included in addition to category 1 properties, variations in headroom availability are evident.

- The impact of heat networks on network headroom is then noticeable in comparison of Figure 14(a) and Figure 14 (b).

- Note that this analysis excludes contributions from local distribution generation i.e., increasing penetrations of renewable generating technologies connected below the primary level are expected to help meet local demand and have an influence on the true demand and thus the true headroom.

Headroom results – Scenario 3

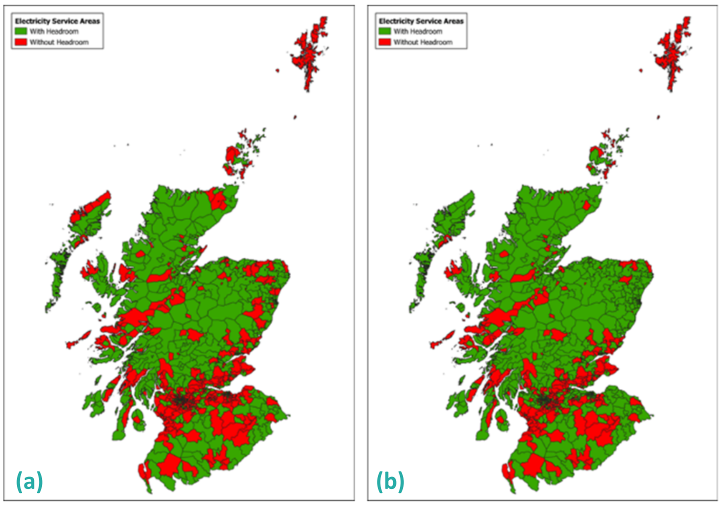

Figure 15:
Headroom for Scenario 3 by ESA:
(a) without heat networks
(b) with heat networks

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- For Scenario 3, which contains category 1 and category 2 properties i.e., a mixture of off-gas properties with a set of building fabric criteria and on-gas properties also with building fabric criteria.

- In Figure 15(a) the ESAs with headroom are increased in typical off-gas areas and ESAs without headroom are increased in on-gas areas in comparison with Figure 14(a). This follows the expected trend for the modelled scenario given the outlined criteria.

Headroom results – Scenario 4

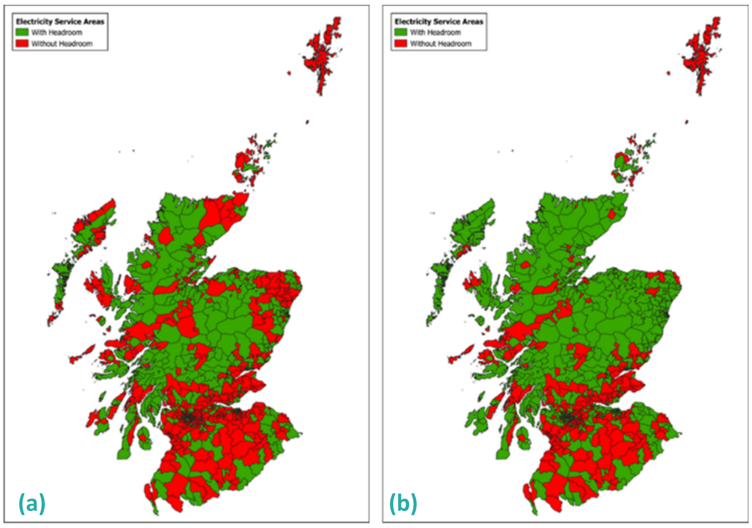

Figure 16:
Headroom for Scenario 4 by ESA:
(a) without heat networks
(b) with heat networks

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- Figure 16 shows geospatial results for Scenario 4, which contains all properties. Again, in comparison of Figure 16(a) and Figure16(b) the ability of heat networks to minimise impact on transformer headroom is demonstrated.

- This ultimately highlights which areas are likely to require reinforcement or a flexible management solution and demonstrates how different decarbonisation pathways can influence the associated investment and planning requirements of electricity network infrastructure in different areas.

Discussion and takeaway:
Integration of electricity network information and local area energy plans

- Understanding of electricity network infrastructure will add value to Local Heat and Energy Efficiency Strategies.
- This must be balanced with the additional complexity it would add and the requirement to develop relationships between local authorities and distribution network operators.

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Integration of Electricity Network Information and Local Area Energy Plans

- The LHEES methodology currently does not include any consideration of local electricity networks as a factor in introducing different heat technology, even though the cost, time and technical barriers discussed will be factors effecting the viability of any given zone or intervention.
- Any attempt to integrate an understanding of electricity network infrastructure will clearly add value to any LHEES plan, but this must be balanced with the additional complexity it would add and requirement to develop relationships between LAs and DNOs.

Value of LHEES and Geospatial Heat Analysis for DNOs

- DNOs undertake their own demand growth modelling exercises as part of their Distribution Future Energy Scenarios (DFES) and to inform their RIIO ED-2 business plans, but cross comparison between their work and this work (and other works) would be valuable.
- Beyond this, the outputs from each regional LHEES, with geographic zones prioritising the different heating technologies identified, will be of particular interest to DNOs. This can offer higher resolution evidence of areas for potential

load growth.

- To derive maximum benefit, meaningful bilateral engagement between both DNOs and LAs to discuss the implications of the LHEES would be beneficial.
- The analysis is carried out at a high-level and as such a number of simplifying assumptions were required. However, the findings ultimately provide a broad outlook of the potential impact from heat pump and heat network uptake across Scotland.
- By carrying out this analysis geospatially, the results provide insight into where investment and additional more localised analysis may be necessary.

Future research opportunities

Local Area Energy Planning - LHEES and Transport Plans

- What evidence is needed for LAs to make choices about heat in buildings?
- How can this information be streamlined for all 33 LAs?

What are the implications of the OFGEM Access Review for Scottish consumers?

- What is the impact on those in fuel poverty?
- What are the worst cases under the new system for off gas and highland and island consumers?

OFGEM and Ahead of Need Investment

- How can Scottish government and LAs work better with DNOs to inform DFES and RIIO?
- What evidence is necessary for OFGEM to approve ahead of need investment?

Future research opportunities

What are the behavioural and economic triggers for changing domestic heating systems?

- To what extent will changes in heating be clustered in space and in time?
- How do these differ for owner occupied, private and housing association homes?

Heat Networks

- How do anchor loads correlate geographically with electricity network infrastructure?
- How can heat networks provide flexibility to the electricity network and wider energy system?

Whole System Hydrogen

- What are the potential pathways for gas grid rollout of hydrogen?
- What transitional plans are necessary under a hydrogen dominant future?

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