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Expanding Scottish energy data - heat

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1 Executive summary

Aims and methodology

The Scottish Government has set ambitious targets to reduce greenhouse gas emissions by 75% by 2030 alongside overarching targets of reaching net-zero emissions by 2045. Achieving these targets will require a wholesale change to Scotland's energy system.

Scotland's electricity sector has been significantly decarbonised through the growth in renewable generation. In 2020 renewable sources of energy provided the equivalent of 98.6% of Scotland's gross electricity consumption.[1] However, despite a high proportion of electricity generation coming directly from renewables, heating of properties is heavily reliant on direct burning of fossil fuels.

The Scottish Government has set targets for the equivalent of 50% of the energy for electricity, heat and transport consumption in Scotland to come from renewable sources by 2030 (estimated at 25.4% in 2020[2]). Access to high quality reliable data is essential in providing the evidence base to inform the development and implementation of effective energy policies and track progress. This report was commissioned to develop new and improved methodologies for collecting and assessing energy data in Scotland in three areas:

- **Weather correcting heat demand:** developing a method to weather correct non-gas heating demand data[3].
- **Heat demand across different fuels and sectors in Scotland:** producing an annual time series of heat demand across different fuel types in the industrial, commercial and domestic sectors. This is space and water heating; process heating in industrial properties is not included. The fuel types investigated were: coal, manufactured fuels, petroleum products, gas, electricity, bioenergy and waste.

[1] Source: Scottish Energy Statistics Hub (shinyapps.io)
[2] Source: Scottish Energy Statistics Hub (shinyapps.io)
[3] Gas demand data is weather corrected to compensate for variations in weather patterns between years (i.e. to adjust gas consumption figures to allow for where weather has been colder or warmer than the seasonal normal).

- **Emissions factors for different heating fuels and sectors:** identifying Scottish specific emissions factors for different heating fuels in order to generate heating emission values for Scotland as a whole.

Findings

Weather correction

The approach applied to weather correct gas demand data maintained by the UK Department for Business, Energy and Industrial Strategy (BEIS) relies on complex mathematical modelling and extensive data. Replicating this approach for other fuel types was not deemed possible in this project. Instead, we draw on degree day information - a measure of how much (in degrees), and how long (in days), the outside temperature was below a certain level in a year to weather correct non-gas heating demand.

Domestic heat demand

The total domestic heat demand (gigawatt hours – GWh) and the average heat demand (kilowatt hours – kWh) for all properties within each fuel type is displayed in Table 1-1. The majority of domestic properties in Scotland are heated by mains gas. There is a significant difference between the average heat demand for each fuel type. Properties using biomass, liquefied petroleum gas (LPG) and oil are more likely to be in rural locations, disconnected from the gas network. They are also more likely to be larger properties, with higher heat demands [1].

Table 1-1: Total domestic heat demand for 2021 for each fuel type and number of properties heated by each fuel type

Fuel	Biomass	Electricity	LPG	Mains Gas	Oil	Total
Total annual heat demand (GWh)	663	4,805	586	25,833	3,678	35,565
Number of Properties	34,224	360,681	27559	2,091,090	174,686	2,688,240
Average Heat Demand for All Property Types (kWh)	19,366	13,321	21,261	12,354	21,054	

Non-domestic heat demand

The total heat demand for each fuel and the average heat demand for all properties within each fuel type are shown in Table 1-2. Electricity is the most popular heating fuel used in non-domestic properties. Properties with less commonly used fuels, such as oil or biomass/coal fuel, tend to have larger heat demands. This may be because these properties are more likely to be in a rural location, not connected to the gas grid and where land is cheaper (and therefore larger).

Table 1-2: Total non-domestic heat demand for 2021 for each fuel type and number of properties heated by each fuel type

Fuel	Electricity	Mains Gas	Oil	Other (Biomass, Coal)	Total

Total annual heat demand (GWh)	5,944	2,545	1,405	373	10,268
Number of Properties	138,963	54,882	26,352	6015	226,212
Average Heat Demand for All Property Types (kWh)	42,772	46,380	53,330	62,068	45,390

Emissions from property heating

Identifying Scottish-specific emission factors for different fuels enables the total heating emissions associated with different fuel types for domestic and non-domestic buildings to be determined.

For domestic properties, the carbon emissions factors along with total emissions from each fuel in 2021 have also been calculated - see Table 1-3.

Table 1-3: Heating emissions from each fuel in domestic properties for 2021

Fuel	Biomass	Electricity (Heat Pump)	Electricity (Other technology)	LPG	Mains Gas	Oil	Total
Heat Total Demand (GWh)	663	302	4,503	586	25,833	3678	35,565
Primary Fuel Energy (GWh)	861	101	4,503	732	32,292	4,597	43,086
Carbon Intensity (Kg CO_2e/kWh)	0.02	0.01	0.04	0.26	0.23	0.31	
Heating Emissions (kT CO_2e/year)	13	4	184	154	5,909	1,149	7,414

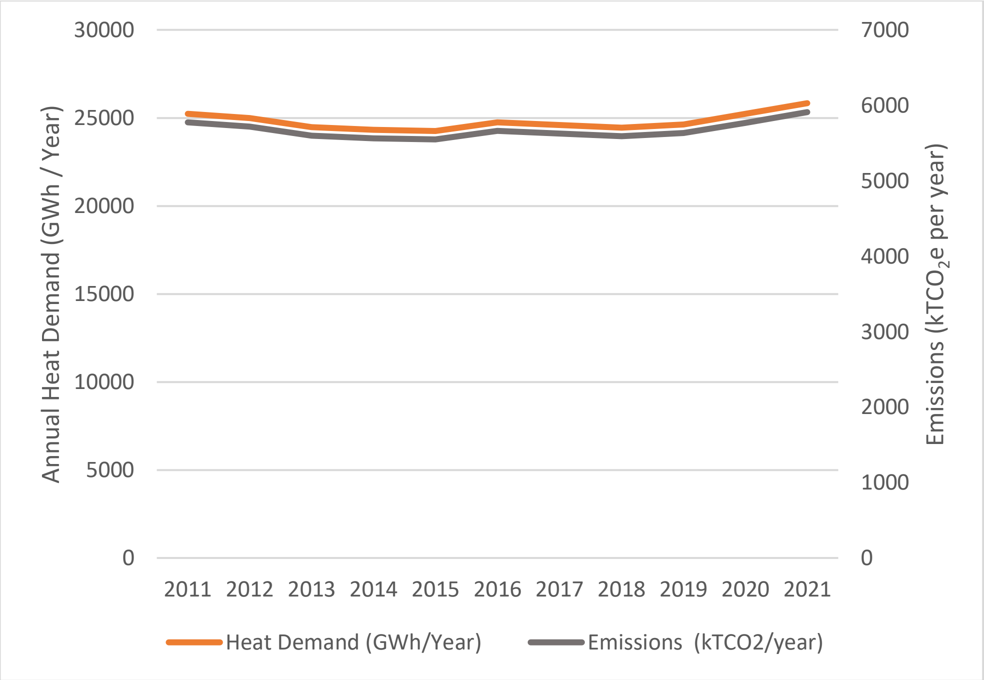
Due to Scotland's relatively low electricity emission intensity[4] and the high efficiency of heat pumps, this analysis highlights that heat demand met with heat pumps is responsible for lower emissions than all other heating fuel sources. Using data from the Scottish House Condition Survey (SHCS), historical results can be generated for how heating emissions from natural gas (

Figure 1-1) and electricity (Figure 1-2) have changed in domestic properties since 2011. Due to the small sample size of the SHCS, for less commonly used fuels, the data was not of sufficient quality to produce historical results.

The domestic heating emissions from natural gas did not increase a significant amount from 2011 to 2021, from 5,775 kTCO_2e a year to 5,909kTCO_2e a year, a rise of 2%, whilst the number of domestic gas-heated properties rose from approximately 1.84 million to 2.09 million, an increase of 14%. Improvements in building energy efficiency appear to have helped offset any significant increase in heat demand associated with an increase in the number of domestic gas-heated properties.

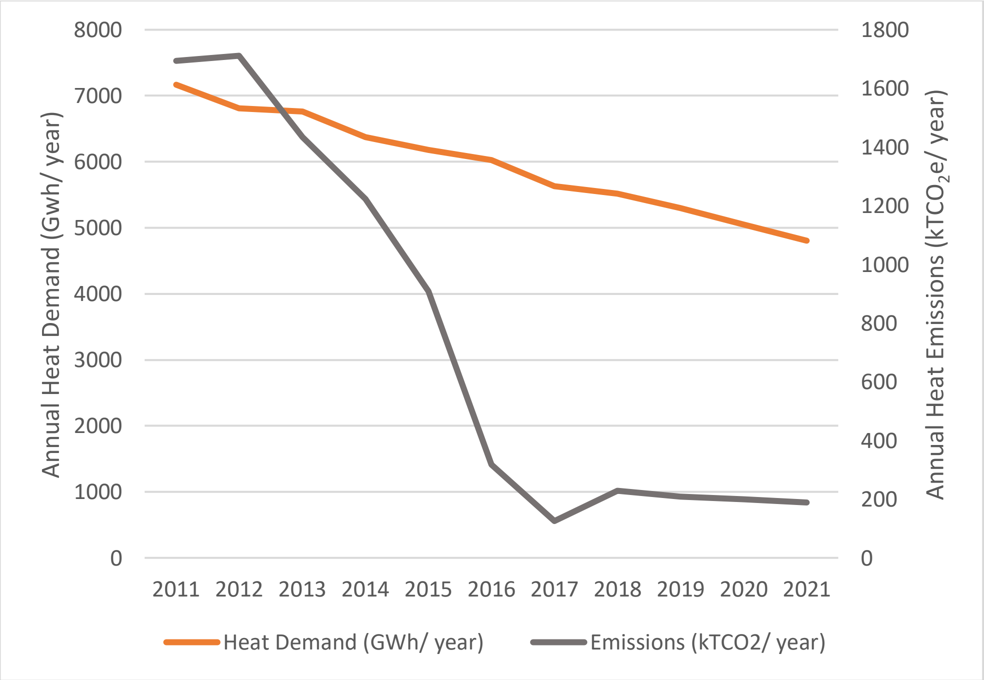
[4] Electrical emission intensity is defined as the average greenhouse gas emissions produced per kWh of electricity delivered. Electricity networks with a higher proportion of electricity produced by low-carbon/ renewable fuels in comparison to fossil fuel power stations will have a lower average electrical emission intensity

Figure 1-1: Domestic heat demand and subsequent emissions in gas-heated properties from 2011-2021



Generating historic figures for emissions associated with domestic electrical heating (Figure 1-2) highlights that although domestic electricity demand for heating fell significantly over the period 2011 to 2021, the decrease in the resultant emissions has been much more rapid. This is primarily due to the significant reduction in the carbon intensity of the electricity grid.

Figure 1-2: Domestic heat demand and subsequent emissions in electric-heated properties from 2011-2021



Recommendations

Several opportunities have been identified to update the models and improve the robustness of the data. These include:

- The datasets embedded into the model for domestic and non-domestic properties could be updated to reflect changes in the building stock in Scotland. We recommend close engagement with the Energy Saving Trust (which manages the Home Analytics and Non-Domestic Analytics dataset) to establish how frequently the datasets are updated and update the model accordingly. This would enable the model to be updated to reflect changes in the sources of fuel used to meet heating requirements of domestic and non-domestic buildings.
- Extending the need for an improved EPC record to an increasing number of domestic and non-domestic properties in Scotland would reduce the degree of modelled data used in Home Analytics and Non-Domestic Buildings Energy Database. This would increase the reliability of data linked to heating fuel sources used in particular housing types.
- It is recommended that the degree days and heat loss coefficient tiers are reviewed every five years, as it is highly unlikely that the change in building stock going forward will change the assumptions by a significant margin over the short term. This will impact on the energy requirements in the home, which will impact on how much energy each fuel type will need to deliver.
- The efficiencies assumed for boilers carrying different fuel types will need to be monitored in the future in order to estimate how much energy the fuel types need to deliver from the primary side to meet the energy requirements of a building at the secondary side. A conservative estimate has been used for estimating the boiler efficiencies for different fuel types. We recommend that the Scottish Government liaises with manufacturers of boilers that use different fuels to understand and track data on boiler efficiency.
- The Scottish Government should consider the sources used in this report to keep track of the carbon intensity figures for different fuel types.
- More data is required on the heat demand and energy efficiency of non-domestic properties. This may be achieved over time as the Non-Domestic Buildings Energy Database is updated with non-domestic EPC records.

Contents

2 Introduction

Project context

The Scottish Government has set ambitious targets for reducing greenhouse gas (GHG) emissions in Scotland by 75% by 2030 alongside overarching targets of reaching net-zero emissions by 2045. Achieving these targets will require a wholesale change to Scotland's energy system.

Scotland's electricity sector has been significantly decarbonised through the growth in renewable generation. In 2020 renewable sources of energy provided the equivalent of 98.6% of Scotland's gross electricity consumption [2]. However, despite a high proportion of electricity generation coming directly from renewables, heating of properties is heavily reliant on direct burning of fossil fuels.

The Scottish Government has set targets for the equivalent of 50% of the energy for electricity, heat and transport consumption in Scotland to come from renewable sources by 2030. Having access to high quality reliable data is essential in providing the evidence base to set effective energy policies and track progress. This includes quality data relating to heat demands and the emissions intensity of heat sources.

Ricardo Energy & Environment (Ricardo) was commissioned by ClimateXChange on behalf of the Scottish Government to develop new and improved methodologies for collecting and assessing heat demand and emissions data.

The purpose of the assessment was to develop a methodology to address the following three key areas:

- **Work package 1: Weather correcting heat demand -** Applying weather correction processes to non-gas heating demand data
- **Work package 2: Heat demand across different fuels and sectors in Scotland -** An annual time series of heat demand delivered across coal, manufactured fuels, petroleum products, gas, electricity, bioenergy and waste across the domestic and non-domestic sectors
- **Work package 3: Emissions factors for different heating fuels and sectors -** Scottish specific emissions factors for different heating fuels in order to assist in calculating the carbon intensity of heat.

3 Data sources & approach

The project sought to develop methodologies for collecting and assessing energy data that can be repeated by the Scottish Government in future years. To achieve this, energy data was collected from various sources (see Section 3.1.1) and processed in Excel to develop methodologies to track the heat and carbon emissions in the building sector.

The project approach was split into two main sub-tasks, which were carried out in parallel:

- Identification and collection of energy data
- Methodological development to enable a better understanding of heat demand and heating fuel emission factors in Scotland

The following sections discuss the data sources collected for the analysis and methodology deployed to answer the key project questions for each sub-task.

A parallel project was carried out focusing on understanding more about electricity demand[5] and focused on the following:

- Estimating an annual time series electricity consumption for heating and non-heating purposes in electrically heated properties
- Estimating an annual time series for heat pump electricity consumption
- Estimating low-carbon energy consumption in the transport sector

The methodology for estimating heat demand associated with different fuel types and sectors uses the same approach for determining electricity consumption for heating in domestic and non-domestic building to that developed in the parallel 'Expanding Scottish Energy Data (Electricity Demand)' project.

Weather correction of heat demand

Gas demand data is weather corrected to compensate for variations in weather patterns between years (i.e. to adjust gas consumption figures to allow for where weather has been colder or warmer than the seasonal normal). This allows annual gas demand data to be compared in different locations where the weather conditions may have differed. The weather correction processes used for gas demand data is undertaken by Xoserve on behalf of Department for Business, Energy & Industrial Strategy (BEIS).

The weather correction process is applied to the UK Energy Consumption dataset for gas demand data which is maintained by BEIS. Having explored the dataset and methodology further with BEIS and Xoserve to identify if we could apply it to other heat fuel types we identified that Scottish data is less well represented and the methodology involves complex mathematical modelling on years' worth of collected meter point data. For this reason, an alternative approach was adopted to compensate for weather variations when determining non-gas fuel types. This approach which involved estimating degree days, which is explained in Section 3.2.2.

Heat demand from different fuel types

The aim of this work package was to develop a repeatable methodology by which the Scottish Government can estimate the total heating demand delivered by different fuel types along with their carbon intensity. This section explains the methodology developed to answer the key project question.

3.1.1 Data sources for different heating fuels

An initial step was to identify existing data sources that can provide information about heating demand data with sufficient granularity. Data sources considered for the analysis were as follows:

Table 3-1 List of data sources considered to estimate the total heating demand delivered to building types from different fuel types

Data sources reviewed	Relevance to the project
Home Analytics (HA)	Home Analytics (HA) is a software package developed by the Energy Saving Trust (EST) for the Scottish Government. It provides information on a wide range of variables pertaining to the Scottish housing stock. It draws on a variety of data sources, predominantly the domestic Energy Performance Certificate (EPC) database as well as other datasets such as the Home

[5] **Electricity Report weblink when available**

Data sources reviewed	Relevance to the project
	Energy Efficiency Database (HEED) and Warmer Homes Scotland (WHS) data. The dataset contains information on approximately 2.7 million domestic properties. Approximately 57% of the data is based on recorded domestic EPC data, with the remainder of the information being modelled. EPCs are certificates which are required whenever a property is built, sold, or rented. An EPC contains information about the property's estimated energy demand and energy efficiency which is estimated using the SAP methodology. A property is assigned an energy efficiency rating from A (most efficient) to G (least efficient) and is valid for 10 years. Information on the energy use and efficiency of the building from existing EPC records is the most useful information within HA. The variables that have been obtained from HA and used in this project are detailed in Table 3-2.
Non-Domestic Analytics Database (NDA)	NDA is a dataset developed by the EST. The dataset covers non-domestic properties in Scotland. This dataset contains information on over 226,000 non-domestic properties in Scotland. Similarly, to HA, it contains information on a wide range of property characteristics and the estimated energy consumption / efficiency of these properties. Less than 15% of the non-domestic properties in Scotland have non-domestic EPCs available. As a result, NDA has a large percentage of data (85%) that is modelled. This results in a less accurate dataset than HA. However, it provides a detailed overview of non-domestic Scottish properties, and as a result, it has been used as the primary source of information for non-domestic properties in this project. Recorded non-domestic EPC records in their low numbers are skewed towards urban areas which indicates that energy performance data in urban areas is based on measured data collected onsite. In contrast, there is less measured data in rural areas, and as a result, the non-domestic EPC records are not representative of the non-domestic portfolio. This resulted in the NDA dataset being implemented which uses statistical modelling to reduce this skew and create a more representative dataset of Scotland's non-domestic property portfolio.
Scottish House Condition Survey Data (SHCS)	The SHCS is a survey that is conducted annually by the Scottish Government and contains data on a wide range of housing related topics. It contains information on variables such as property type, property age, SAP band, main fuel type and main heating technology type as well as others. The survey is based on a small sample size, approximately 3,000 properties, and is scaled up to be representative of Scotland as a whole. A representative sample from the SHCS was provided to the Ricardo project team with historical results on different fuel types. This has allowed historical figures to be calculated for domestic Scottish properties by using the results at the present time in HA as the baseline to track backwards.

As discussed in Table 3-1, both HA and NDA have a significant amount of data that is modelled, that could not be obtained from existing datasets. These models use a variety of address-level predictors such as property type, age, tenure, urban/rural classification and number of habitable rooms. They also use area-level indicators, known as "neighbourhood measures", to estimate a variable based on measured variables of nearby properties. A weighting is applied to these measures, based on the proportion of known records in the area. A postcode with 90% known records would be more influential than one which only had 10% known records. The variables from HA and NDA that have been used in this project are detailed in

Table 3-2: and

Table 3-3.

Table 3-2: A list of data types in the HA dataset which were used for developing a methodology to estimate total heat demand delivered by different fuel types in domestic properties.

Field Name	Description
Local authority (LA)	This contain the local authority area where the property is located.
Property type	The property type of each domestic property was included in the assessment. These included: • Detached house • Semi-detached house • Mid-terraced house • End terraced house • Small block of flats / property converted into flats – This property could be within a low-rise block or be a flat within a house that has been converted. • Flat in mixed use building – This is a flat that is within a building that also contains non-domestic units, such as a flat above a shop. • Block of flats – This is a flat within a block, not the entirety of the block. • Large block of flats – This is a flat within a larger tower.
Total floor area estimate (m^2)	An estimate of the properties floor area was provided, which meant that this could be factored in when estimating heat loss coefficient to predict heating demand
Main fuel type	The primary fuel type used to heat the property. This project is focused on all heating fuel types.
Standard Assessment Procedure (SAP) rating band	The energy efficiency (SAP) rating band of the property. This includes bands • A-B • C • D • E • F-G • Unknown
Heat demand estimate (kWh/year)	An estimate of the property's annual heat demand at the current SAP rating, which includes space and water heating.
Total energy consumption estimate (kWh/year)	An estimate of the property's annual energy consumption at the current SAP rating, including electricity and heating demand split between space water heating.

Field Name	Description
Confidence estimate	This is a number between 0-1, which indicates the level of accuracy of the modelled results for each variable

Table 3-3: Information provided in the NDA provided by the Scottish Government

Field Name	Description
Local authority (LA)	This contain the local authority area where the property is located.
Property Type	Categories include: • Restaurants and Cafes • Retail and Financial Services – E.g. shops / financial services such as banks. • General Industrial, Storage or Distribution – E.g. warehouses and depots. • Offices and Workshops - E.g. offices and small-scale manufacturing premises. • Hotels • Residential Institutions and Spaces – E.g. care home, hospitals, and prisons. • General Assembly – E.g. factories. • Non-residential Institutions – E.g. museums, libraries, and law courts. • Other – Any non-domestic property that cannot be categorised into the classifications discussed above
Total floor area estimate (m^2)	An estimate of the properties floor area, used to calculate the Heat Transfer Coefficient for each property type (detailed in Section 3.2.2)
Main fuel type	The primary fuel type used to heat the property. This included the following: • Electricity • Mains Gas • Oil • Other (Includes biomass and solid fuels)
Space heating demand estimate (kWh/year)	An estimate of the property's annual space heating demand
Water heating demand estimate (kWh/year)	An estimate of the property's annual water heating demand. For non-domestic properties, NDA includes space and water heating split out as separate variables. In HA they are combined into one variable.
Main heating system	The includes: • Air heater • Boiler • Heat Pump • Room heater • Other (CHP, radiant heaters or district heating system)

HA was selected as the primary data source for carrying out the analysis of the domestic properties in Scotland at the present time, which is supplemented by the SHCS which provides historical trends. It is important to note that HA and the SHCS provide a similar set of data, although they arrive at it via different methods. HA's is far more granular, with much greater detail regarding the property location and its characteristics. However, the data in HA is skewed, due to its reliance on data captured as part of the EPC process. Properties in urban areas, new-builds and rental properties are all more likely to have had EPCs undertaken than the average property. Such property types are likely to be overrepresented in the dataset.

The SHCS is arguably more representative; its main disadvantage is the small sample size. Due to the small sample size, made even smaller when filtering for properties with a specific heating fuel type, year-on-year results for specific property types could fluctuate significantly, likely more than reality. A benefit of the SHCS, in comparison to HA, is that it excludes unoccupied properties and second homes. As HA does not exclude these properties, there is a risk that using this dataset could lead to energy consumption being overestimated.

As a result of the different methodologies used to derive these two datasets there are some inconsistencies between them. For the most recent data available, for 2019, the SHCS identifies approximately 275,000 electrically heated domestic properties in Scotland, whereas HA 2021 data contains approximately 360,000 of these properties. In addition, there are approximately 2,091,090 gas heated properties recorded in HA for 2021 while 2,015,000 are recorded in SHCS. Although this data is for different years, given that the number of electrically heated properties from 2011 to 2019 decreased by an average of 2% per year, it is unlikely that from 2019 to 2021 this figure would have subsequently increased by over 30%. It is more likely that this discrepancy is due to differences in the methodology used to compile the two data sources.

Due to the high granularity of HA we adopted this dataset as the primary source of data for the model to estimate the energy consumption at the present time, while the SHCS was used to generate historical trends which creates the annual time series. However, a second model was also provided to the Scottish Government that uses data input from the SHCS to allow the flexibility to interchange between both datasets as the main inputs in the model. The results of this secondary model are discussed in detail in Section 4.

3.1.2 Methodological development

Estimating the total heating demand delivered to a property to meet its energy requirements depends on a number of factors:

- **Total Heating Demand of the Property:** A property's space and water heating requirements are dependent on factors such as the type and size of the building, occupancy, demographics, floor area, the energy efficiency of the building, location and preference of the occupants.
- **Heating Technology Installed:** The type of heating technology installed at the property will impact on the amount of heat that can be delivered to a property.

Our approach to calculating the total heating demand of a property involved estimating the following:

- **Calculating heating degree days:** This is the measure of how much (in degrees) and how long in days the outside temperature was below a certain level [3]. Degree days are commonly used in calculations relating to estimating the energy consumption required to meet the heating requirements of the building type. To estimate this, the outside temperature was collected from Met Office stations across every local authority area in Scotland and using a sensible base temperature of 15.5 degrees Celsius the difference between the indoor and outdoor temperature can be estimated each hour and summed to predict total degree days for the year. The base temperature of a building is the outside temperature below which the building requires heating. It is calculated as the difference between the desired internal temperature, and the internal gains from other non-heating system sources such as occupants and appliances. In the UK, a typical desired internal temperature is 19°C, and it is assumed that internal gains make up 3.5°C. Therefore 15.5°C is the conventional base temperature for the UK [4].

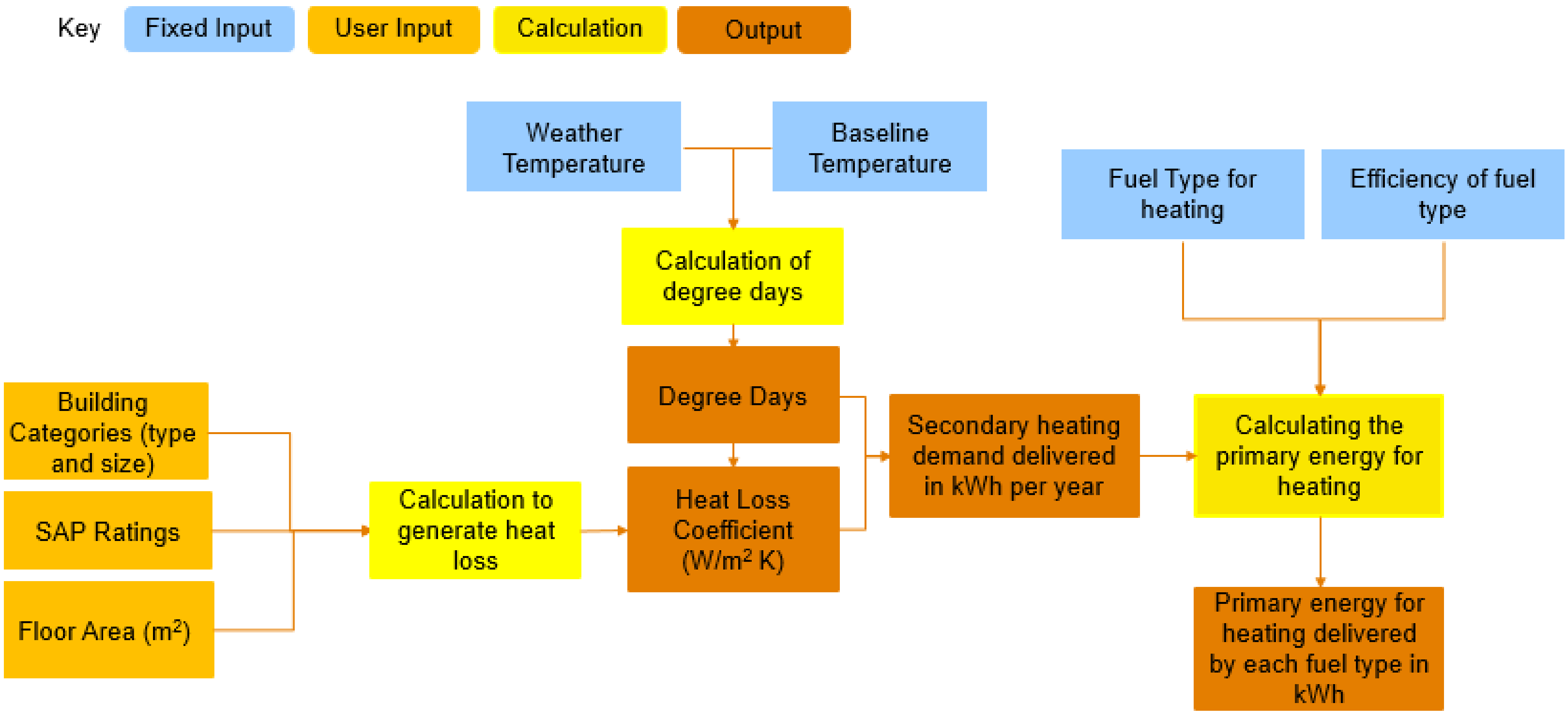
- **Calculating heat transfer coefficient:** Heat transfer coefficient of a building determines the rate of heat transfer between the building envelope when a temperature difference exists between the indoor and outdoor temperatures. The heat transfer coefficient was estimated using variables in HA and NDA such as the average heat demand and SAP rating of each property type alongside the average floor area for each property. This allowed heat transfer coefficient numbers to be assigned to different tiers, which is the assignment of an estimated average heat loss coefficient value to each property type.
- **Calculating total heat demand:** The total annual heat demand for each property type was calculated by using a combination of the degree days for each local authority and the appropriate heat transfer coefficient from the different tiers which varies for different property types. This represents the secondary heating demand, which is the amount of energy the building requires.
- **Efficiency of different heating technologies:** The efficiency of the main heating fuel varies across different technology types. In this case, the efficiency of different heating fuel types was estimated from data sources available online. Section 0 discusses this further.
- **Calculating total primary heating demand delivered:** Estimating the total secondary heating demand can be used along with the efficiency of the technology to determine the primary heating demand. The primary heating demand is the amount of heat energy that the fuel type must deliver which is greater than the overall secondary heating requirements of the property in order to cater for the efficiency of the heating technology type.

Generating heat transfer coefficients for each SAP band and property type was not possible for non-domestic properties. The lower quality data available for non-domestic properties resulted in the heat transfer coefficients that were generated for the non-domestic SAP band tiers being unrealistic.

The methodology deployed above is further illustrated in the flowchart diagram below for an individual property.

In addition to the above, data provided by representatives of the SHCS tracks how the number of fuel types uses for heating has changed, split by property type, SAP band and heating technology over the years. The primary and secondary heating demand delivered to a property category was calculated for the present-day situation and extrapolated using the historical trends presented by the SHCS to generate annual time series figures.

Figure 3-1 Flow diagram showing the methodology deployed to estimate the total heat demand from different fuel types for individual properties



Carbon intensity of different fuel types

In addition to the heat demand for different fuels, this study produced estimates for the carbon emissions associated with each fuel type. These carbon emissions, in combination with typical efficiencies of the respective heating technologies, allow for the carbon intensity of each heating mode to be calculated in kilograms of carbon dioxide (CO_2e) per kilo watt hour (kWh) of heat energy delivered to a property.

3.1.3 Data sources

To carry out the analysis of the carbon intensities of different fuels, a mix of publicly available sources was used. Table 3-4 provides details about the sources used.

Table 3-4: Carbon intensities data sources

Data sources reviewed	Relevance to the project
Energy statistics for Scotland	The energy statistics for Scotland was used in conjunction with Scottish renewables and the Scottish climate change plan to arrive at a value for the Scotland specific emissions associated with grid electricity. Energy Statistics for Scotland is a website maintained by the Scottish Government which provides statistics on Scotland's energy performance, in particular the proportion of electricity that is generated from renewables [5].
Scottish renewables	This dataset provides information on energy consumption by sector in Scotland [6].
Scottish climate change plan	As above.
UK Government greenhouse gases conversion factors	The UK Government greenhouse gases conversion factors were used for the remaining fuel types analysed in this study. The values obtained from this source give the associated emissions of a kWh of primary energy [7].
Specialist sources to determine different heating technology efficiencies	The efficiencies of heating technologies were taken from relevant sources, such as scientific papers, specialist publications and equipment specifications. These are referenced in the sections below [8] [9] [10] [11].

3.1.4 Methodology

Electricity

For electricity, the carbon intensity is dependent on the generation mix that is producing electricity across the electricity grid at the time of use. The type of fuel used in the generation plant and the efficiency of conversion determine the amount of CO_{2e} per kWh of electricity delivered to the grid.

England, Scotland and Wales are all connected to the same electricity transmission system (the GB grid). However, on a net basis, Scotland generates around 96% of its electricity needs from renewable energy sources and therefore the generation mix in Scotland is significantly less carbon intense than the overall GB grid [2]. For this assessment, carbon intensity figures based on electricity generation in Scotland have been applied.

The Scottish government set a target to have a carbon intensity of less than 0.050kgCO_2e/kWh and the electricity mix is expected to be consistently below this figure from 2020 onwards [5]. Historical grid intensity values are available at Energy statistics for Scotland. This has fallen from 0.238kgCO2e/kWh in 2011 to 0.041kgCO_2e/kWh in 2019 [12]. The respective historical carbon intensity value has been used for each year when calculating historic heating emissions for electrically heated homes. The historical carbon intensity values for the Scottish grid are displayed in Table 3-5.

Table 3-5: Historical carbon intensity factors for the Scottish grid (2011-2019)

Year	Carbon Intensity Factor (kgCO2e/kWh)
2011	0.2379
2012	0.2539
2013	0.2149
2014	0.1953
2015	0.1500
2016	0.0539
2017	0.0229
2018	0.0429
2019	0.0409

Assuming 100% efficiency of conventional electric heaters, the grid intensity number could be used for every kWh of heat delivered. If a heat pump with a Seasonal Coefficient of Performance (SCOP) of 3 is used, the figure would fall to 0.014kgCO_2 /kWh.

Natural gas

According to the UK Government's GHG conversion factors, natural gas emits 0.183kgCO_2e/kWh of primary energy [7].

New condensing boilers reach efficiencies of over 90% (sources suggest that new boilers can be as high as 94% efficient) [8]. However, older condensing boilers are not as efficient as modern ones - a 10-year-old boiler is expected to provide heating with 80-85% efficiency, while a 20-year-old one would be 75% efficient [8]. The Scottish House Condition Survey in 2019 found that 64% of boilers are standard compliant and meet the required efficiency of 88% [13]. While no reliable information about the average efficiency of natural gas boilers could be obtained, a conservative assumption of 80% will be used for the modelling process.

As a result, heating emissions of 0.229kgCO_2e/kWh were calculated for natural gas.

Biomass and solids

The HA data set used to carry out this analysis combines biomass and solid fuels under the same category when presenting statistics for the primary heating fuel. Coal was assumed to be the only solid included in this category. Currently there are around 14,000 homes in Scotland that still use coal as their primary heating source [6], while approximately 1% of domestic properties in Scotland from HA are supplied by biomass/solid fuels as the main fuel type.

The emissions associated with biomass and coal are 0.015kgCO_2e/kWh and 0.34kgCO_2e/kWh respectively [7]. For biomass, the net emissions are taken into the calculations, which consider the offsetting effect of growing the biomass.

There are varying estimates for the efficiency of biomass boilers. A conservative estimate of 77% based on a trial was adopted [11]. Similarly, for coal heating systems, sources suggest varying efficiencies. Biomass and solid fuels both burn in a similar boiler, and are ventilated in the same way, we have therefore assumed the same figure for overall efficiency

The resulting carbon intensity per unit of heat delivered is 0.02kgCO_2e/kWh for biomass and 0.442kgCO_2e/kWh for coal.

Liquefied Petroleum Gas (LPG)

An emissions intensity of 0.21kgCO_2e/kWh of primary energy was taken for LPG from Greenhouse gas reporting: conversion factors 2021 [7]. Given the heating technology would be very similar to those used for natural gas, the same heating efficiency figure of 80% has been adopted.

The resulting carbon intensity per unit of heat delivered is 0.263kgCO_2e/kWh.

Oil

For rural properties that are off the gas grid, oil is the most commonly used heating fuel [14]. The emissions intensity per unit of primary energy of oil is 0.25kgCO_2e/kWh [7]

Similarly, to natural gas, condensing boilers are used for oil heating, and the same assumption about the proportion of older heating systems and the rates of adoption of newer technologies can be made. Therefore, the same efficiency of 80% could be assumed for oil boilers

The resulting carbon intensity per unit of heat delivered is 0.313kgCO_2e/kWh.

4 Research results

This section presents the results of the modelling. Two iterations of this model have been designed, one using input data from HA/NDA and one using input data from the SHCS.

HA Model

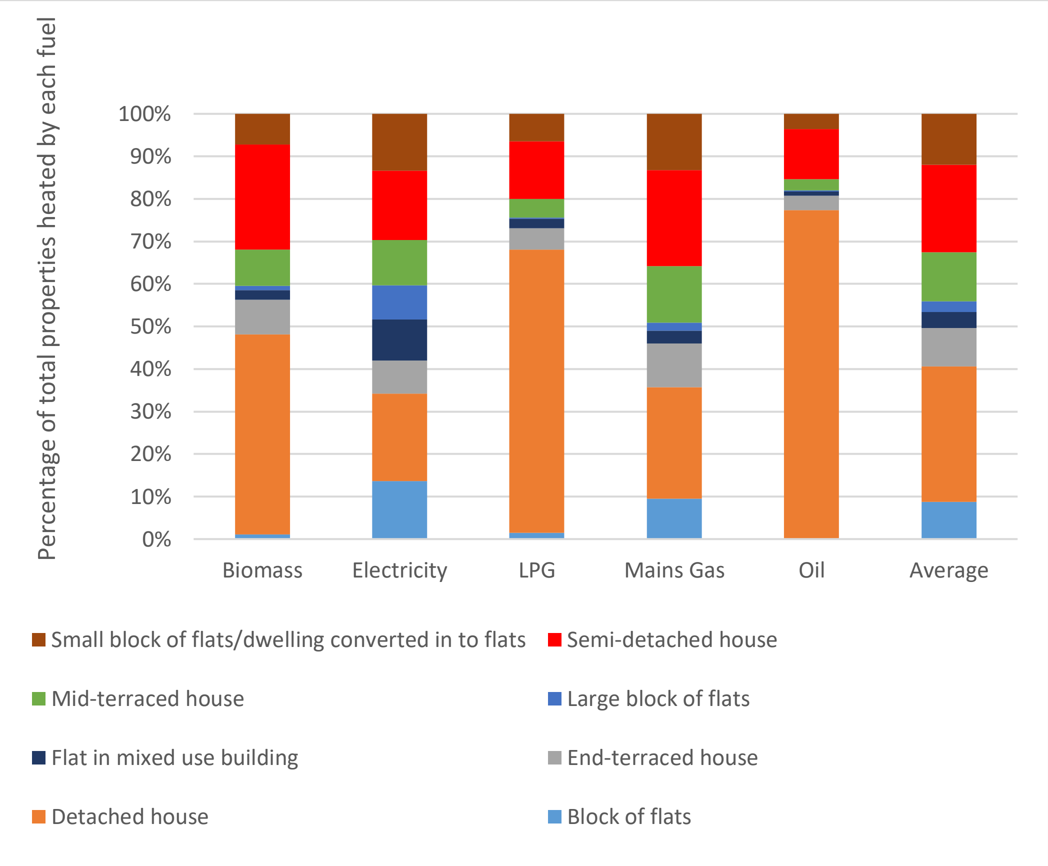
Utilising each property type's heat transfer coefficient and each Local Authority's specific degree day value, a typical heat demand for each property can be estimated. Information from HA was extracted to establish the number of each property type using each heating fuel. The total heat demand delivered by each fuel type was estimated for 2021 for each domestic property type (see Table 4-1).

Table 4-1: Total domestic heat demand for 2021 for each fuel type and number of properties heated by each fuel type

Fuel	Biomass	Electricity	LPG	Mains Gas	Oil	Total
Total annual heat demand (GWh)	663	4,805	586	25,833	3,678	35,565
Number of Properties	34,224	360,681	27,559	2,091,090	174,686	2,688,240
Average annual heat demand (kWh)	19,366	13,321	21,261	12,354	21,054	13,230

Table 4-1 shows that amount of domestic heat supplied by each property type varies significantly between the different fuels, with the majority of properties being supplied by natural gas. However, the average annual heat demand of each of these properties also varies significantly. Properties heated by biomass, LPG and oil tend to have significantly higher average heat demands, which is because these properties tend to be larger properties in rural locations that are not connected to the gas grid. Figure 4-1 highlights that larger properties (detached houses) are more likely to be heated by LPG, biomass or oil whilst smaller properties (flats) are more likely to be heated by mains gas or electricity.

Figure 4-1: Percentage of fuel demand from each domestic property type



Due to the dominance of mains gas as a heating fuel in Scotland, the average figure closely resembles the Mains Gas bar. Using generic efficiencies for each heating fuel, discussed in Section 3.1.4, the primary energy required for each heating fuel can be calculated, as shown in Table 4-2.

Table 4-2: Annual heat demand and primary energy demand for each heating fuel for 2021

Fuel	Biomass	Electricity (Heat Pump)	Electricity (Other technology)	LPG	Mains Gas	Oil	Total
Heat Total Demand (GWh)	663	302	4,503	586	25,833	3,678	35,565
Primary Fuel Energy (GWh)	861	101	4,503	732	32,292	4,597	43,086
Heating Emissions ($kTCO_2e$/year)	13	4	184	154	5,909	1,149	7,414

Using the primary fuel energy for each fuel type, from Table 4-2 and the carbon intensities calculated in 3.1.4 (shown in Table 4-3), annual emissions produced by heating for each fuel type can be calculated. Natural gas makes up the largest share of the emissions from heating in Scotland, making up 80% of carbon dioxide emissions. Emission intensities for each fuel are displayed in Table 4-3.

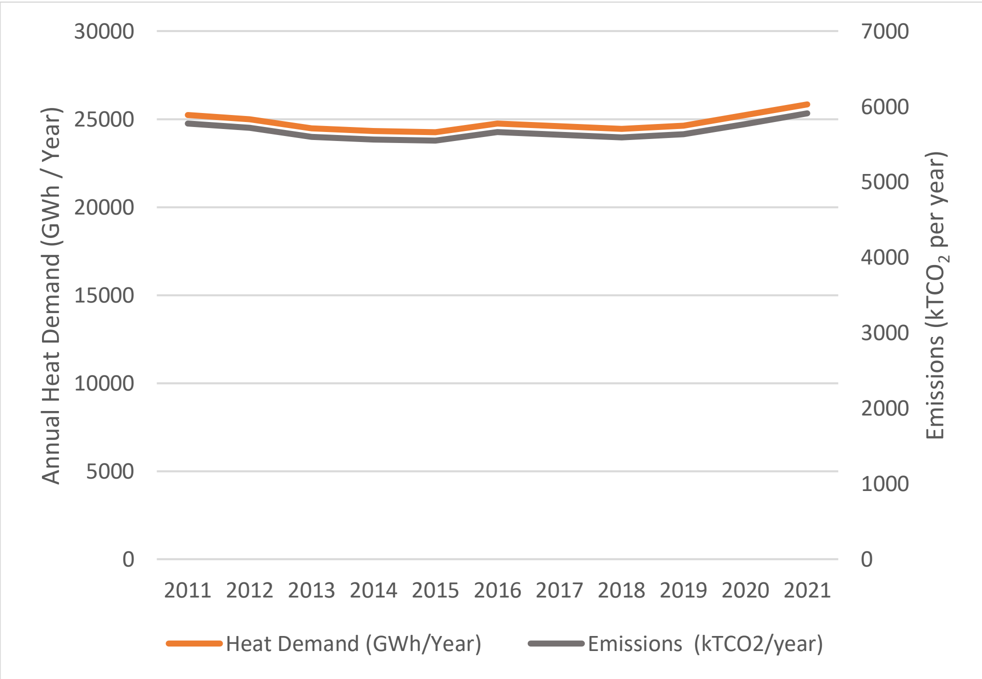
Table 4-3: Emission intensities for each heating fuel

Fuel	Oil	LPG	Mains Gas	Electricity (Other technology)	Biomass	Electricity (Heat Pump)
Emission Intensity ($kgCO_2e/kWh$)	0.313	0.263	0.229	0.041	0.019	0.014

Using data from the SHCS, historical results can be generated for how heating emissions from natural gas and electricity have changed in domestic properties since 2011.

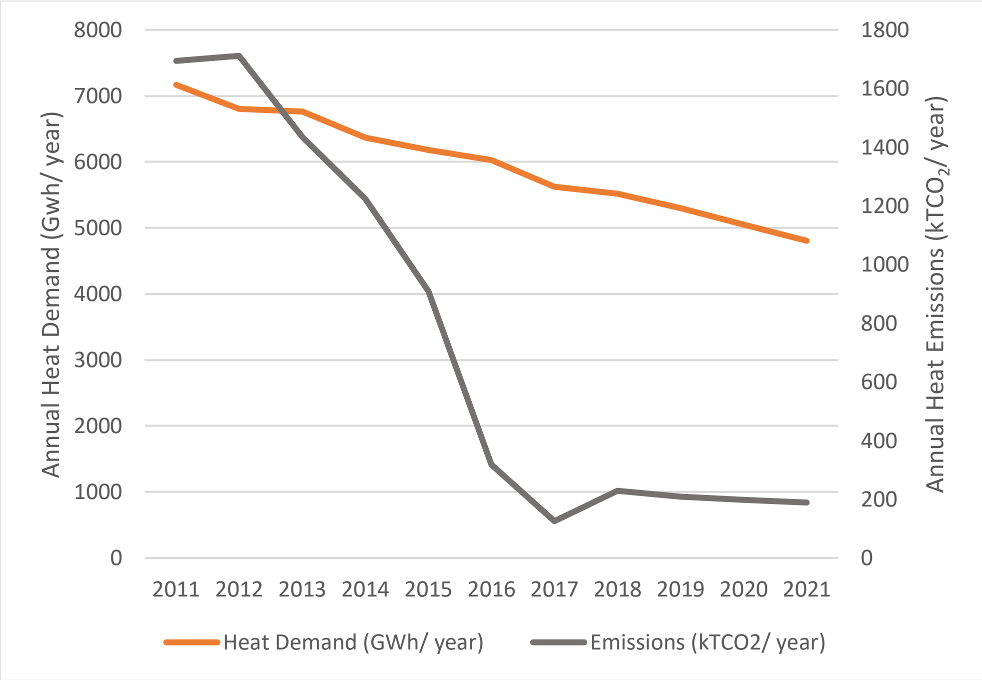
Figure 4-2 shows how the emissions from domestic gas-heated properties have changed in Scotland over time. The domestic heating emissions from mains gas heating have not increased significantly from 2011 to 2021, from 5,775 $kTCO_2e$ a year to 5,909$kTCO_2e$ a year, an increase of 2%. Over this period the number of domestic gas-heated properties has increased from approximately 1.84 million to 2.09 million, an increase of 14%. Emissions increased at a slower rate than the number of gas -heated properties as buildings have become more energy efficient, with their SAP rating increasing in the model, resulting in lower heat demand. The increase in heat demand and emissions from 2019 to 2021 may be affected by using HA for the inputs for 2021. There is a discrepancy of the number of gas-heated properties for the most recently available data for the SHCS and HA, with HA containing 76,000 extra properties. Analysis is presented in Section 0, without using input data from HA to mitigate this.

Figure 4-2: Domestic heat demand and subsequent emissions in gas-heated properties from 2011-2021



Historical figures of heat demand and emissions associated with domestic electrical heating can be generated using the model (Figure 4-3). The graph highlights that although domestic electricity demand for heating fell significantly from 7,167GWh in 2011 to 4,805GWh in 2021, the decrease in the resultant emissions has been much more rapid. This has decreased from 1694kTCO$_2$e to 188kTCO$_2$e. This is primarily due to the significant reduction in the carbon intensity of the electricity grid from 0.2379kgCO$_2$e/kWh in 2011 to 0.0409kgCO$_2$e/kWh in 2019 (most recently available data [12]). For this analysis, it has been assumed that the carbon intensity in 2019 is the same as 2020 and 2021. The increase visible from 2017 to 2019 is due to a rise in electricity produced from natural gas power plants. This is a result of long-term outages at the nuclear power station, Hunterson B. This figure of 0.0409kgCO$_2$e/kWh is significantly lower than the UK's grid intensity, 0.169kgCO$_2$e/kWh [12]. In addition, the installation of heat pumps has increased from generating 1% of heat in domestic electrically heated homes in 2011 (83GWh) to 6% in 2021 (302GWh).

Figure 4-3: Domestic heat demand and subsequent emissions in electric-heated properties from 2011-2021



HA contains information on domestic properties that are heated by communal heating systems. The heat demand and resultant emissions for each fuel, in communal heating systems, is shown in **Error! Reference source not found.**.

Table 4-4: Heat demand and emissions for domestic properties using communal heating systems 2021

Fuel	Biomass	Electricity	LPG	Mains Gas	Oil	Total
Heat Total Demand (GWh)	44	62	1	120	8	235
Primary Fuel Energy (GWh)	57	21	1	150	10	239
Heating Emissions (kT CO_2e/year)	0.86	0.84	0.26	27.36	2.55	31.88

For this analysis it has been assumed that electrically heated communal systems are using heat pumps. The same efficiencies used throughout this analysis are used to calculate the emissions of communal heating systems by non-electric fuels. The analysis indicates that 86% of the emissions from domestic communal heating systems in Scotland are produced by natural gas.

NDA Model

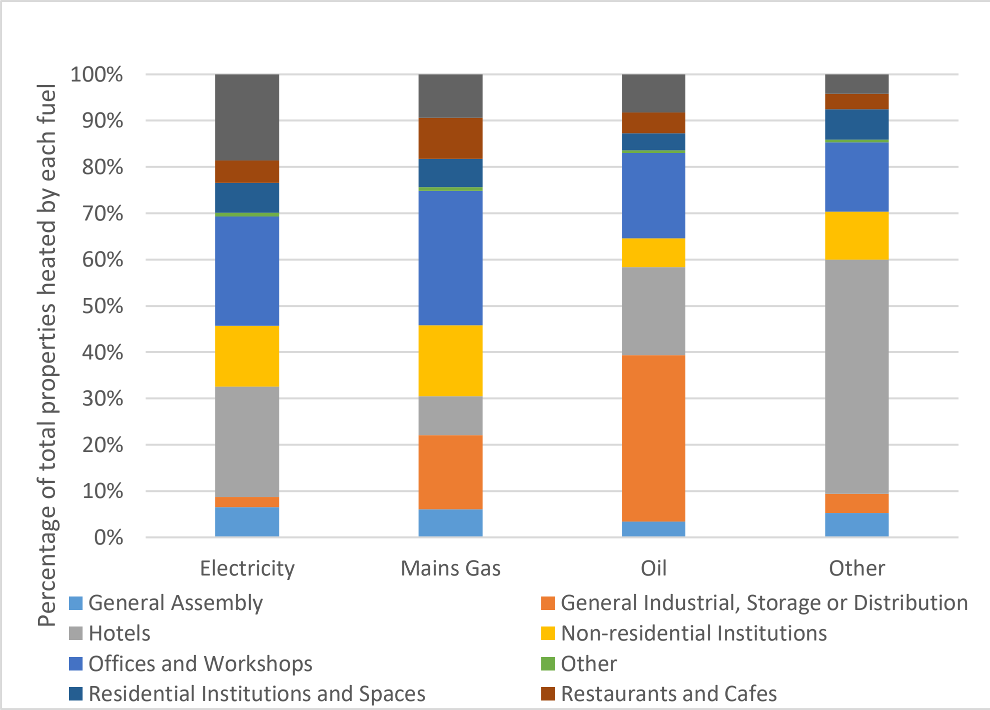
The heating emissions of non-domestic properties has also been analysed. The total heat demand for each fuel, the resultant primary energy required to meet this demand and the average heat demand per fuel are shown in Table 4-5. The fuel categories in NDA are different to the categories in HA. There is another fuel category that encompasses the lesser used fuels (biomass and coal). Table 4-5 shows that properties with less commonly used fuels such as oil or an "other" fuel tend to have larger heat demands. Similarly, to the HA model this may be a result of these properties being more likely to be in a rural location, not connected to the gas grid, where land is less expensive. They are therefore more likely to be larger buildings, with a higher heat demand. Electricity is the most popular heating fuel used in non-domestic properties.

Table 4-5: Total non-domestic heat demand for 2021 for each fuel type and number of properties heated by each fuel type

Fuel	Electricity	Mains Gas	Oil	Other (Biomass, Coal)	Total
Total annual heat demand (GWh)	5,944	2,545	1,405	373	10,268
Number of properties	138,963	54,882	26,352	6,015	226,212
Average Heat Demand for All Property Types (kWh)	42,772	46,380	53,330	62,068	45,390

Further evidence of this is shown in Figure 4-4, properties heated by oil are more likely to be larger properties in categories such as General Industrial, Storage and Distribution. The most common property type heated by "other" fuels is hotels, this is likely hotels in rural areas of Scotland.

Figure 4-4: Percentage of fuel demand from each non-domestic property type



In order to calculate the emissions generated by the heating of non-domestic properties, the emission intensities shown in Table 4-3 were utilised. It is not possible to generate emissions for the "other" category. Instead, data from the BEIS Consumption database was used [15]. In this dataset, in 2019 (the most recently available data) for non-domestic buildings, for every GWh of heat provided by coal, approximately 2.2GWh of heat were provided by biomass. It was assumed that this split was representative of the "other" category and used to generate a heat demand for biomass and coal. This is an estimate as this split is for the entirety of the UK, Scotland-specific data on this was not available.

See Table 4-6 for the heat demand, the primary fuel required to meet this demand and the total emissions from each heating fuel for non-domestic properties.

Table 4-6: Total non-domestic heat demand for 2021 for each fuel type and number of properties heated by each fuel type

Fuel	Mains Gas	Oil	Electricity (Other technology)	Solid Fuel	Electricity (Heat Pump)	Biomass and Waste	Total
Heat Total Demand (GWh)	2,545	1,405	5,177	116	767	258	10,268
Primary Fuel Energy (GWh)	3,182	1,757	5,177	150	256	322	10,844
Heating Emissions ($kTCO_2e$/year)	582	439	212	51	10	5	1,299

For non-domestic properties, the heating fuel contributing the most to emissions is mains gas, although the largest heat demand comes from electrically heated properties. Solid fuels supply approximately 15% of the heat demand from non-domestic heat pumps but have emissions over five times larger than heat pumps. There was no data available to generate historic results for non-domestic properties.

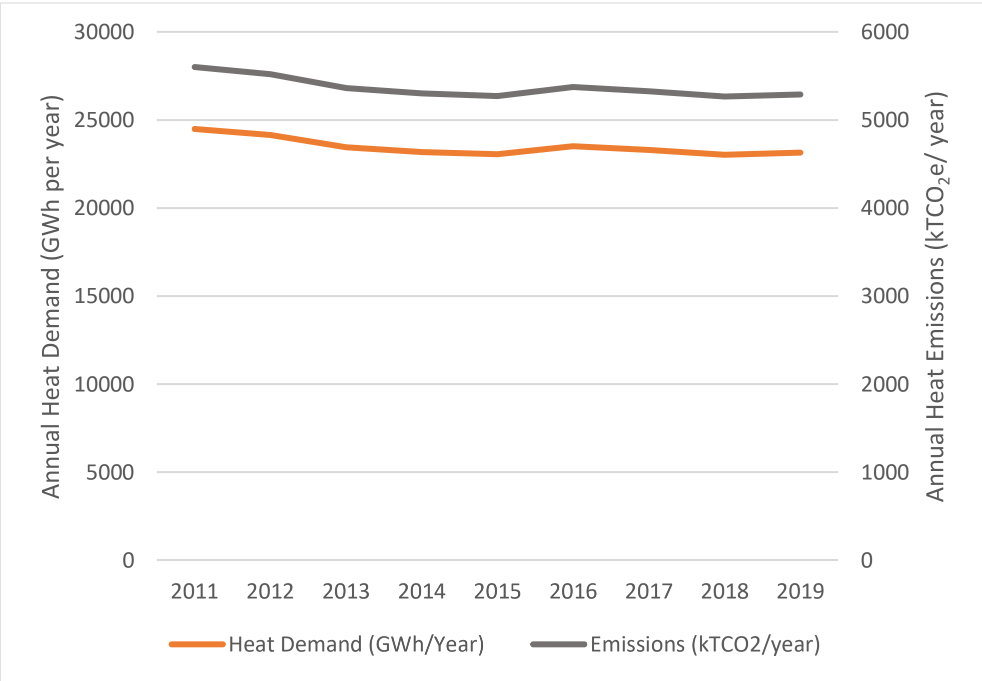
There are some important caveats to the NDA model. Due to a lack of available measured data, a high proportion of the data (over 85%) is modelled. This reduces the overall reliability of the data. Another potential issue is the significant variety in size and heat demand of a specific non-domestic property type. For example, the size and heat demand of a non-residential institution could vary significantly, making it difficult to assign a characteristic Heat Transfer Coefficient to it. In contrast, the heat demand of a semi-detached house, although still variable, will have significantly less deviation from the average. These issues result in the non-domestic portion of the model being less reliable than the domestic aspect.

SHCS Model

The Scottish Government requested a version of this tool to be developed using input data from the SHCS too. As mentioned previously, the data for lesser used fuels was not reliable enough to generate historic results. Historic results have been generated for electrical heating and gas heating from 2011-2019 (most recently available data). The emissions from gas heated domestic properties in this time-frame are shown in Figure 4-5.

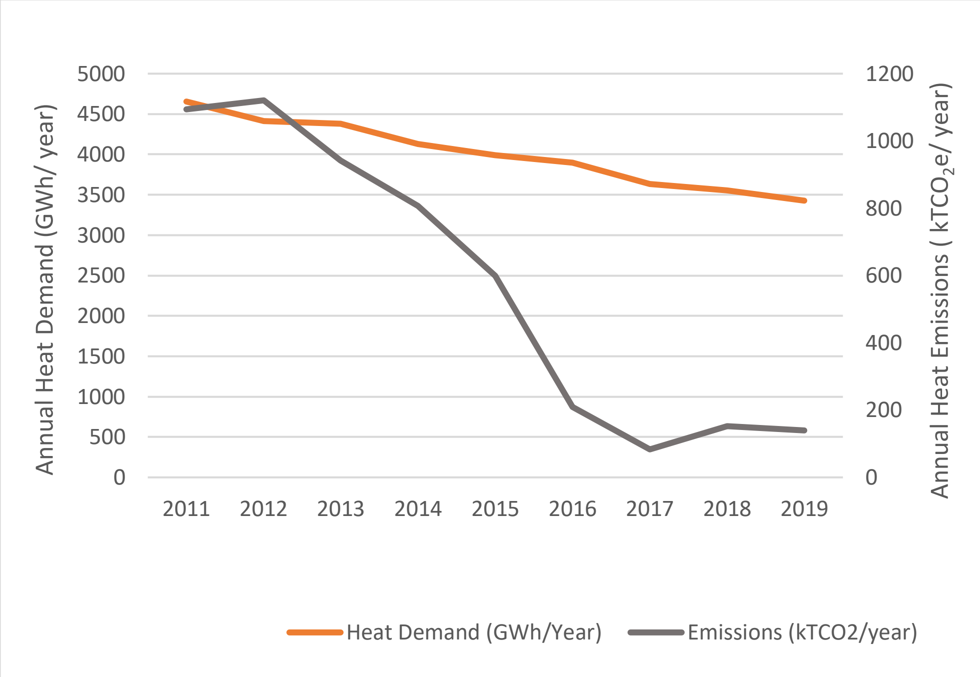
The amount of gas heated properties in the HA model and the SHCS model is relatively similar. The total number of gas-heated properties has increased from 1.81 million to 2.01 million in this time frame. Heat demand has decreased from 24482GWh per year to 23127GWh per year and the subsequent emissions have decreased from 5600kTCO_2e per year to 5290kTCO_2e per year. Despite an increase in the number of gas-heated properties heat demand and emissions have decreased as a result of increases in overall building energy efficiency over this period is a result.

Figure 4-5: Domestic heat demand and subsequent emissions in gas-heated properties from 2011-2019- SHCS Model



For electrically heated properties, in this same time frame, the number of properties has fallen from 335,000 to 259,000 with heat demand falling from 4656GWh/ year to 3427GWh/ year. Due to the large reduction in the carbon intensity of the Scottish grid, and the increased prevalence of heat pumps, the emissions have fallen from 1094kTCO_2e/ year to 140kTCO_2e/ year. Similarly, to Figure 4-3, this has increased slightly, from a low in 2017 due to the increase in the grid's carbon intensity in recent years. These results are illustrated in Figure 4-6.

Figure 4-6: Domestic heat demand and subsequent emissions in electrically heated properties from 2011-2019- SHCS Model



Comparison of results

4.1.1 Comparison of domestic results

For domestic properties, the results from the model that uses HA data differs to those when the SHCS data is used. BEIS has high quality data available for gas heating in domestic properties, recorded as meter point data [16]. The results of the two models in this study can be compared to the data published by BEIS, although this only pertains to gas consumption and is therefore an imperfect assessment of the accuracy and reliability of the models. See

Table 4-7 for a comparison of the historical results generated by the HA model, the SHCS model and from the meter point BEIS data. The most recent BEIS data available is for 2019. The gas consumption for the HA model and the SHCS models have been calculated by dividing the heat demand by the assumed efficiency of a gas boiler, 80%, discussed in Section 3.1.4.

Table 4-7: Comparison of historical gas consumption from the two models and BEIS Meter data

Year	SHCS Model- Gas Consumption (GWh/ year)	HA Model- Gas Consumption (GWh/ year)	BEIS Meter Point Gas Consumption (GWh/ year)
2011	30,602	31,555	28,959
2012	30,168	31,253	28,802
2013	29,309	30,602	28,073
2014	28,969	30,397	27,700
2015	28,802	30,316	27,442
2016	29,370	30,919	27,804
2017	29,096	30,747	28,496
2018	28,772	30,543	28,349

2019	28,909	30,764	28,823

On average the results of the SHCS and HA models are 3.8% and 8.2% higher respectively than from the BEIS data. It appears both models are more accurate in more recent years, the deviation for 2019 specifically is 0.3% for the SHCS model and 6.7% for the HA model. A similar dataset exists for domestic electrical consumption, but this is not specific to heating and includes electrical consumption for domestic appliances. Therefore, the total electric meter point data for BEIS will be significantly higher than the electrical heating consumption figures. Given the high degree of similarity between both models and the gas meter point data, it is reasonable to assume that the electrical heating demand and the subsequent emissions calculated by this model are also relatively conclusive but not definitive.

The Scottish Government also publish historic data on non-electrical domestic heating. It has not been possible to generate historic figures for fuels other than gas and electricity for these models as explained previously. For the SHCS model, the only “non-electric” heating fuel is gas, so the comparison is not worthwhile. See Table 4-8 for a comparison of the domestic non-electrical heating demand for the HA model and for the results published by the Scottish Government [17].

Table 4-8: Comparison of non-electrical heating in HA model and published results from the Scottish Government

HA Model- Domestic Non-electric Heat Demand (GWh)- 2021	SG Data- Domestic Non-electric Heat Demand (GWh)- 2019
30,760	34,546

The estimates of non-electric heat demand produced using the HA model are 11% lower than data published by the Scottish Government. There are several potential reasons for this discrepancy. One is that the most recent figures from the Scottish Government are for 2019, and this will be compared against the 2021 figures for the HA model. It is also possible that the Scottish Government data is less reliable than the BEIS gas meter point data. Fuels such as coal, biomass and oil are not metered and therefore any results have a significant degree of uncertainty.

Published data for heating emissions from the Scottish residential sector is not available; however, data for total emissions per sector is published.

Table 4-9 shows a comparison of total emissions from the Scottish residential sector and the domestic heat emissions calculated in the HA model [18].

Table 4-9: Comparison of domestic heating emissions in HA model and published results from Scottish Government

HA Model- Domestic Heating Emissions ($kTCO_2e$)- 2021	SG Data- Domestic Emissions ($kTCO_2e$)- 2019
7,414	6,200

When comparing Table 4-8 and

Table 4-9, it is noteworthy that although the heat demand in the model is lower than the published figures by the Scottish Government, the domestic heating emissions in the model are higher than the total domestic emissions from the Scottish published data. Given the similarities shown in

Table 4-7 and to an extent, Table 4-8, this would indicate that the methodology used to produce Scottish emission data may differ from the one in this model.

4.1.2 Comparison of non-domestic results

The NDA model discussed in this report calculates the space and water heating for non-domestic properties. The process heating used in industrial properties is not factored in. The Scottish Government's "industry" figures for heating demand include process heating. For the purposes of this analysis, the heat demand from "commercial" properties is used.

Table 4-10: Comparison of non-domestic non-electrical heat demand using the NDA model and Scottish Government data

NDA Model- Non-domestic Non-electric Heat Demand (GWh)- 2021	SG Data- Non-domestic Non-electric Heat Demand (GWh)- 2019
4,324	13,502

This figure is significantly different to the figure generated for non-domestic properties in the model. The 13,502GWh figures is also not entirely representative of the Scottish heat demand of non-domestic properties as it does not include space/ water heating in industrial properties. The limitations of the NDA model have been discussed in detail in this report previously. The primary reasons for the lesser accuracy of the NDA model is the low percentage of recorded data in NDA along with the large variety in non-domestic property types. An "office and workshop" property category or "non-residential institution" can vary in size and therefore heat demand significantly, it is difficult to assign a characteristic heat transfer coefficient to a single property type.

5 Key considerations for future datasets

We devised a methodology for estimating energy needs that relies on specific information that characterises property types and provides estimates of their energy needs. The reliability of our assessment hinges directly on the availability of information providing:

- A satisfactory level of detail
- Good coverage of the domestic and non-domestic building stock in Scotland
- High levels of confidence in the data

However, obtaining data that meets all these criteria was not possible.

The three main sources of information for this study were HA, NDA and SHCS. These data sets collate available data from EPC certificates for domestic and non-domestic properties respectively. Any gaps in the existing data are filled by modelled results. Extrapolating the EPC results to fill gaps introduces room for error, and, further to this, the EPC data itself is known to suffer from some inaccuracies. Naturally, larger proportions of measured data provide a fuller picture and lead to less modelling being necessary, and, thus, more representative results. Lower proportions of measurements require larger number of properties to be modelled, where both the increased role of modelling and the relative scarcity of information from measured data magnify potential errors.

- HA is a robust data set where about 57% of the data comes from EPC certificates. Furthermore, the variation between domestic properties' size and energy demand is low (in comparison with non-domestic properties), so the data set was deemed representative.
- NDA provides a much less comprehensive picture of non-domestic properties in Scotland. The measured data amounts to about 15% of the total, with the rest of the data set relying on modelling. The negative impact of this is further

compounded by the significant variability in the size, demand and usage profile of non-domestic properties.

While historic and present-day data cannot be improved, its limitations and potential improvements can be explored to aid future data collection. Such improvements to both domestic and non-domestic property data collection are discussed in this section.

Data for domestic properties

The SAP methodology and the resulting EPC is an effective way to capture comprehensive data about a property. However, it should be recognised that reliance on EPC information suffers from significant drawbacks:

- Not all properties have an EPC. They have been required since 2008 for new builds and any property being rented or sold. This creates a skew in the EPC data towards new builds and properties that have actively participated in the market since 2008. Older buildings that have not been marketed in one form or another are less represented in EPC data.
- The gap in EPCs for old properties that have not participated in the market recently will likely be slow to fill. Unless a campaign to produce an EPC for each property is carried out or these properties suddenly appear on the market en masse (both events are unlikely), full data about domestic properties in Scotland would need to continue to rely on modelled results for a significant proportion of properties.
- EPC assessors are expected to capture a significant amount of data in a short space of time. This leads to some inaccuracies that have been recognised, specifically when it comes to building fabric quality and the resulting heat demand.

Nevertheless, EPCs and modelled data in HA are likely to remain a major source for updates to the spreadsheet software to capture the installation of heating arrangements from different fuel types resulting from this study.

There is further scope to improving the data collection for domestic properties that use coal, manufactured fuels, petroleum products and bioenergy. These fuels are likely to be sold and delivered by a certified supplier. Introducing a short questionnaire that accompanies deliveries of these fuels could begin to paint a more accurate picture of what the overall heat demand that these sources meet is. The questionnaire could capture:

- Property type
- Type of heating that the new heating fuel has replaced
- EPC band (if available)

Another possible way to improve the data capture about properties using coal, manufactured fuels, petroleum products and bioenergy would be to ensure a proportional number of these properties is captured in the SHCS each year compared to just capturing properties being supplied by natural gas and electricity. Surveying a certain overall proportion of properties is bound to capture only a small number of biomass heated properties for example, as they form a small overall percentage. Setting up the survey so the same proportion of each different heating technology is sampled would produce more reliable results and, thus, it will improve the quality of the present analysis. The limitations of the SHCS were the low number of heating fuels recorded with the exception of gas and electric. As a result, it was not possible to generate historical numbers due to the lack of reliable trends from the modelling exercise.

Data for non-domestic properties

Unlike domestic properties, non-domestic ones tend to vary significantly in their type of use, size, demand, usage profile. In addition to space heating and hot water demand, certain premises would also have process heat demand.

This variability results in difficulties in assigning properties into small number of high-level categories to perform an analysis on their heat demand.

Further to this, NDA, which was the main source of information regarding non-domestic properties, is made up of around 15% EPC data and 85% modelled data. This proportion allows for significant margin of error as very limited available data is extrapolated to cover the entirety of non-domestic premises in Scotland

To bridge the gap between the available data and the data required to carry out a robust analysis, more data about heat demand and energy efficiency in non-domestic properties from different fuel types would need to be captured. This could take the form of:

- An approach to increase the number of EPCs
- Capture limited information through business rates – self reporting
    - Size of premises
    - Type of premises – choose from limited categories
    - Type of heating system
    - Tick boxes on space, hot water and process heat
- Collaborate with zero waste Scotland's energy efficiency business support service to capture limited information.

6 Findings and conclusions

Key data sources for both domestic and non-domestic properties were identified and used in conjunction to produce characteristic Heat Transfer Coefficients for different property types. Due to the small sample size of the SHCS respondents using heating fuels that are not mains gas or electricity, it was not possible to generate reliable historical results for fuels other than mains gas and electricity. A lack of historical non-domestic data prevented the generation of historical non-domestic figures. Two domestic models have been developed during this project. One is using HA as the source for the number of properties whilst the other uses the SHCS. A non-domestic model has also been developed using NDA as the primary data source for the number of non-domestic properties. They key findings of these models are as follows:

6.1.1 HA Model - results

The present-day annual heat demand and subsequent emissions from each fuel in the domestic sector based on this model are as follows:

- Mains Gas: 25,883GWh- 5,909kTCO_2e
- Electrical heaters: 4,503GWh- 184kTCO_2e
- Oil: 3,678GWh- 1,149kTCO_2e
- Biomass: 663GWh- 13kTCO_2e
- LPG: 586GWh- 154kTCO_2e
- Heat Pumps: 302GWh- 4kTCO_2e

The total domestic heat demand is 35,565GWh and total domestic heat emissions are 7,414kTCO$_2$e. The total emissions from mains gas heating have increased from 5,775kTCO$_2$e to 5,909kTCO$_2$e from 2011-2021. The total emissions from electrical heating have decreased from 1,694kTCO$_2$e to 188kTCO$_2$e. This large decrease is primarily due to the significant reduction in the carbon intensity of the Scottish electricity grid; however, the increasing usage of heat pumps has also played a role.

6.1.2 SHCS Model - results

The domestic heat demand from mains gas has fallen from 24,482GWh in 2011 to 23,127GWh in 2019 whilst the subsequent annual emissions have decreased from 5,600kTCO$_2$e to 5,290kTCO$_2$e. For electrical heating, the domestic demand has fallen from 4,656GWh in 2011 to 3,427GWh in 2019 whilst emissions have decreased from 1,094kTCO$_2$e to 140kTCO$_2$e.

6.1.3 NDA Model - results

The present-day annual heat demand and subsequent emissions from each fuel in the non-domestic sector based on this model are as follows:

- Electrical heaters: 5,177GWh- 212kTCO$_2$e
- Mains Gas: 2,545GWh- 582kTCO$_2$e
- Oil: 1,405GWh- 439kTCO$_2$e
- Heat Pumps: 767GWh- 10kTCO$_2$e
- Biomass: 258GWh- 5kTCO$_2$e
- Solid fuels: 116GWh- 51kTCO$_2$e

The total non-domestic heat demand is 10,268GWh and total domestic heat emissions are 1,299kTCO$_2$e. Due to the lower quality non-domestic data and the larger variation in the size of non-domestic properties, this model is likely less accurate than the domestic model.

Recommendations

Several opportunities have been identified to update the models and improve the robustness of the data. These include:

- The datasets embedded into the model for domestic and non-domestic properties can be updated to reflect changes in the building stock in Scotland. We recommend close engagement with the EST (which manages the HA and Non-Domestic Building dataset) to establish how frequently the datasets are updated and revise the model accordingly. Changes in the number of domestic and non-domestic buildings that have their heating needs supplied by different fuel types could be used to update the model.
- Extending the need for an improved EPC record to an increasing number of domestic and non-domestic properties in Scotland would reduce the degree of modelled data used in HA and Non-Domestic Buildings Energy Database. This would undoubtedly be beneficial and would increase the reliability of that particular housing type being supplied by a heating fuel type.
- Reviewing the degree day information and heat loss coefficient tiers every five years. It is highly unlikely that the change in building stock going forward will change the assumptions by a significant margin over a short time period. This will

impact on the energy requirements in the home, which will impact on how much energy each fuel type will need to deliver.

- Keeping track of developments in boiler efficiency for boilers that use different fuel types as this will impact on the scale of fuel demand to meet heating needs.
- The Scottish Government should consider the sources used in this report to keep track of the carbon intensity figures for different fuel types.
- More data is required on the heat demand and energy efficiency of non-domestic properties. This may be achieved over time as the Non-Domestic Buildings Energy Database is updated with non-domestic EPC records.

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8 Appendices

Appendix 1: Data sources

HA is a software package developed by the EST for the Scottish Government. It draws on a variety of data sources, predominantly the domestic EPC database. It also utilises data from other datasets such as the Home Energy Efficiency Database (HEED) and Warmer Homes Scotland (WHS) installation data, amongst many others. The database contains 2,730,781 unique rows, which is the number of domestic buildings there are in Scotland. Approximately 57% of the data is based on recorded domestic EPC data, whilst the remainder is modelled. The Release Notes for HA provided a very detailed discussion regarding the methodology to produce the database. It provided a detailed step-by-step guide into how the data from different sources was merged and what statistical techniques were used to model the most likely values for gaps in the data. It also provides information on how accurate the modelled results are for each variable.

NDA is a similar dataset to HA, which has also been developed by the EST for non-domestic buildings. There is a non-domestic EPC database available, however its coverage is significantly smaller. Approximately 15% of non-domestic buildings have EPC data available. Therefore, the NDA package has a far greater percentage of data “modelled” than observed. This contrasts with HA, where the majority of the data is observed. NDA uses the same methodology as HA. There are some differences in the outcomes, however the NDA release notes highlights that due to the much more limited size of the datasets available, the figures can be very skewed towards urban areas and new builds. The significantly larger amount of modelled data instead of observed data for NDA makes the majority of their results less accurate than HA. However, it is likely this is the most accurate source available at the present time and more accurate than purely using non-domestic EPC data, which will have no measures in place to correct biases.

The Scottish House Condition Survey (SHCS) is a survey that is conducted annually by the Scottish Government and contains data on a wide range of housing related topics. It contains historical data on how the domestic property portfolio has changed in Scotland, including how the energy performance has varied over the years and how the choice of heating technology has varied. HA, although comprehensive, is a snapshot of the housing stock at the present time and does not show the historical trends in energy consumption from different heating fuel types. Data was acquired from the SHCS to show historical trends into the percentage of different domestic heating fuel types that has varied with time. This was then used to estimate historical figures for heating consumption from the fuel types. The SHCS is based on a small sample size of less than 3000 properties, which has been scaled up by the survey team at the Scottish Government to translate the numbers into national numbers, which were used for this analysis.

An equivalent dataset to develop historical trends for non-domestic building types does not exist.

Appendix 2: Methodology development

8.1.1 Inputs

This section provides a more detailed description of the methodology used to produce the results in Section 4. Within the tool, developed as part of this project, there are Input pages for both domestic and non-domestic properties. These Input pages have been initially populated by the HA and NDA datasets for the respective domestic/ non-domestic input pages. See and for examples of the Input pages for domestic and non-domestic properties. Input pages allow the Scottish Government to update the tool if the building stock changes. Information that can be included in the input pages relating to each property:

- Property type
- Main heating technology
- Location (Local Authority)
- SAP band rating (domestic properties only)

For both domestic and non-domestic properties, information about a building's property type, location and main heating technology can be entered. The domestic input page also contains information about a property's SAP band rating.

The table below shows the number of domestic properties where their primary heating requirements are being meet by different fuel types in the LA area of Aberdeen City.

Table 8-1: Total number of domestic properties in Aberdeen City that are fitted with different primary heating sources of energy to heat the properties.

Total count of different heating technology types that are present in domestic properties in the LA of Aberdeen City						
Domestic Type	**Biomass / Solid Fuel**	**Electric**	**LPG**	**Mains Gas**	**Oil**	**No Fuel**
Block of flats	12	5,282	84	26,324	5	357
Detached house	42	319	159	10,788	647	93
End-terraced house	10	508	21	9,000	35	24
Flat in mixed use building	16	3,012	12	4,069	19	85
Large block of flats	15	6,522	4	6,033	2	436
Mid-terraced house	26	899	38	14,464	42	48
Semi-detached house	33	683	57	15,384	120	33
Small block of flats/dwelling converted in to flats	24	1,779	56	14,801	48	160

In this case, as expected, mains gas is the dominant fuel type for supplying a range of domestic properties heating requirements.

Similarly, for non-domestic properties, the total count is provided below. Note this is for a much smaller sample of data and is not representative of Aberdeen City as a whole.

Table 8-2: Proportion of heating technologies that are installed in non-domestic buildings in Scotland

Total count of different heating technology types that are present in nond-domestic properties in Aberdeen City				
Non-domestic Type	**Electric**	**Mains Gas**	**Oil**	**Other (Biomass, Waste & Solid Fuel)**
General Assembly	117	81	6	1
General Industrial, Storage or Distribution	76	361	522	4
Hotels	316	152	4	5
Non-residential Institutions	358	216	14	7
Offices and Workshops	1,363	1,395	313	10
Other	89	38	3	
Residential Institutions and Spaces	127	53	5	3
Restaurants and Cafes	286	220	25	2
Retail and Financial Services	1,837	377	139	8

8.1.2 Data sources - further discussion

Table 8-3 provides a comparison between the two datasets to highlight key differentiating points.

Table 8-3: Comparison between HA and the Scottish Housing Condition Survey

Differentiating point	Description
Sample size	• HA is based on EPCs which cover 57% of the housing stock, data for the remaining properties is modelled. • SHCS is based on a small sample size- approximately of 3,000 domestic properties and the results are extrapolated.
Accuracy of the sample data	• HA is based on EPCs that could be old, skewed towards new builds and rentals • SHCS is based on annually updated sample that is representative of the country.
Representativeness of the total number of buildings	• HA covers all domestic properties in Scotland • SHCS looks at occupied dwellings and excludes long term unoccupied and second homes, thus providing a more accurate representation
Geographical representation	• HA contains information on the exact address of each property, can be split by Local Authority • SHCS does not provide annual data for Local Authorities, this data is averaged over three years
Building characteristics	• HA provides detailed information about EPC rating, energy consumption and detailed building characteristics • SHCS provides information on limited building characteristics and EPC bands
Ease of updating the tool	• SHCS is updated annually, these figures can be input into the tool on an annual basis to easily update the model on a regular basis. • Home Analytics is a dataset provided by an outside contractor; it is not necessarily updated annually

8.1.3 Degree days

A key component of this methodology is the utilisation of degree days. Degree days are essentially a measure of the difference in degrees and how many days the outdoor temperature is below a baseline or internal temperature. The base temperature is the desired internal temperature that accounts for solar gains and internal gains. The standardised base temperature for degree days within Europe is 15.5°C. Although this would initially appear too low for a desired internal temperature, solar gains and internal gains from people/ appliances increase this internal temperature above 15.5°C.

We have access to Met Office data for all weather stations across GB. This dataset contains hourly air temperature data for each weather station. Weather stations were selected for each Local Authority in Scotland based primarily on location but also factors such as altitude and quality of the data. Where there was more than one weather station that could be considered representative of the weather patterns in the LA area, the data collected from each station was averaged. Five years of data was extracted and then used to calculate a specific degree day value for each local authority. See Table 8-4 for a list of each Weather Station chosen as representative of each Local Authority. Where there is no suitable weather station in the Local Authority assumptions were made to select the best one for the analysis.

Table 8-4: Weather stations chosen for each Local Authority

Local Authority	Weather Station Used	Notes
Aberdeen City	30910- Dyce, Aberdeen City	
Aberdeenshire	30800- Aboyne, Aberdeenshire 30880- Inverbevie, Aberdeenshire	Data from these two WS in Aberdeen has been averaged together.
Angus	31710, Leuchars, Fife	There is no available WS in Angus. This is closest suitable WS.
Argyll and Bute	31110, Campbelltown Airport, Argyll and Bute 31340, Bishopton, Renfrewshire	There is no available WS in mainland Argyll and Bute. Data from these two WS has been averaged together.
City of Edinburgh	31600, Edinburgh Airport, Edinburgh	
Clackmannanshire	31440, Auchterarder, Perth and Kinross	There is no available WS in Clackmannanshire. This is closest suitable WS.
Dumfries and Galloway	31530, Kirkcudbright, Dumfries and Galloway	
Dundee	31710, Leuchars, Fife	There is no available WS in Dundee with high quality data available. This is closest suitable WS.
East Ayrshire	31360, Glasgow Prestwick Airport, South Ayrshire	There is no available WS in East Ayrshire. This is closest suitable WS.
East Dunbartonshire	31400, Glasgow Airport, Renfrewshire	There is no available WS in East Dunbartonshire. This is closest suitable WS.
East Lothian	31600, Edinburgh Airport, Edinburgh 31580, Duns, Scottish Borders	There is no available WS in East Lothian. Data from these two WS has been averaged together.
East Renfrewshire	31400, Glasgow Airport, Renfrewshire	
Falkirk	31400, Glasgow Airport, Renfrewshire	There is no available WS in Falkirk. Data from these two WS has been averaged together.

Local Authority	Weather Station Used	Notes
	31600, Edinburgh Airport, Edinburgh	
Fife	31710, Leuchars, Fife	
Glasgow City	31400, Glasgow Airport, Renfrewshire	
Highlands	30590, Inverness, Highlands	This was the only representative WS in Highlands, near population centres, with a representative altitude.
Inverclyde	31340, Bishopton, Renfrewshire	There is no available WS in Inverclyde. This is closest suitable WS.
Midlothian	31600, Edinburgh Airport, Edinburgh	There is no available WS in Midlothian. This is closest suitable WS.
Moray	30680, Lossiemouth, Moray	
Na h-Eileanan Siar	30260, Stornoway, Na h-Eileanan Siar	
North Ayrshire	31350, Prestwick, South Ayrshire	There is no available WS in North Ayrshire. This is closest suitable WS.
North Lanarkshire	31400, Glasgow Airport, Renfrewshire	There is no available WS in North Lanarkshire. This is closest suitable WS.
Orkney	30170, Kirkwall Airport, Orkney	
Perth and Kinross	31440, Auchterarder, Perth and Kinross	
Renfrewshire	31400, Glasgow Airport, Renfrewshire	
Scottish Borders	31580, Duns, Scottish Borders	
Shetland Islands	30064, Trondavoe, Shetland Islands	
South Ayrshire	31350, Prestwick, South Ayrshire	
South Lanarkshire	31400, Glasgow Airport, Renfrewshire 31550, Lanark, South Lanarkshire	These two WS have been averaged together as just 31550 was used previously. However, population center of South Lanarkshire is nearer Glasgow.
Stirling	31400, Glasgow Airport, Renfrewshire 31440, Auchterarder, Perth and Kinross	There is no available WS in Stirling. Data from these two WS has been averaged together.

Local Authority	Weather Station Used	Notes
West Dunbartonshire	31340, Bishopton, Renfrewshire	There is no available WS in West Dunbartonshire. This is closest suitable WS.
West Lothian	31600, Edinburgh Airport, Edinburgh	There is no available WS in West Lothian. This is closest suitable WS.

8.1.4 Heat transfer coefficient

Data from HA and NDA was used to calculate average heat demands and average floor areas for each property type. Using this data, specific heat transfer coefficients for each property type can be calculated. For domestic properties, each property type was further broken down into respective SAP bands and each property type/ SAP band combination had a heat transfer coefficient assigned to it. This tier system will enable the Scottish Government to update the inputs, discussed previously, if more efficient properties are built or if older properties are retrofitted to improve their efficiency. This will result in properties moving from a lower SAP band to a higher one. The tier approach was also attempted with non-domestic properties. Unfortunately, due to the significantly smaller quantity of measured data within the NDA dataset, the numbers produced using this method were not realistic. As a result, for non-domestic properties, there is a single heat transfer coefficient for each property type, which are not split by SAP band. As more non-domestic property data become available, the tier system may be viable in a future iteration of the tool. See Table 8-5 and Table 8-6 for the heat transfer coefficients for domestic and non-domestic properties.

Table 8-5: Domestic heat transfer coefficients

Heat Transfer Coefficients (W/m^2K)	A-B	C	D	E	F-G
Block of flats	1.21	1.86	2.67	3.19	3.29
Detached house	1.58	1.94	2.63	3.29	3.80
End-terraced house	1.63	2.23	2.89	3.76	4.21
Flat in mixed use building	1.10	1.61	2.60	3.67	4.00
Large block of flats	1.13	1.45	1.93	1.98	2.78
Mid-terraced house	1.54	2.12	2.80	3.69	3.93
Semi-detached house	1.54	2.11	2.87	3.84	4.28
Small block of flats/dwelling converted in to flats	1.44	1.93	2.84	3.98	4.61

Table 8-6: Non-domestic heat transfer coefficients

Property Type	Heat Transfer Coefficient (W/m^2k)
General Assembly	1.54
General Industrial, Storage or Distribution	1.43
Hotels	4.47
Non-residential Institutions	1.45
Offices and Workshops	1.43
Other	2.76
Residential Institutions and Spaces	2.16
Restaurants and Cafes	3.82
Retail and Financial Services	1.22

8.1.5 Heat demand calculations

Using the heat transfer coefficients, the degree days for each LA and average floor areas for each property type, a characteristic annual heat demand for each property can be calculated. These numbers represent the total heating demand delivered to the property from each fuel type

The total heating demand delivered by each fuel type for domestic and non-domestic properties is provided below.

Table 8-7: Total Heating Demand per domestic property and by each fuel type

Total Heating Demand (GWh) per domestic property type and for each fuel type						
Property Type	**Biomass**	**Electricity**	**LPG**	**Mains Gas**	**Oil**	**Total**
Block of flats	7.4	656	8.7	2,453	4.6	**3,130**
Detached house	312	987	390	6,760	2,842	**11,291**
End-terraced house	55	376	29	2,661	122	**3,243**
Flat in mixed use building	14	463	13	792	37	**1,319**
Large block of flats	7	387	1.8	483	10	**890**
Mid-terraced house	56	512	25	3,443	95	**4,132**
Semi-detached house	164	778	80	5,821	434	**7,276**
Small block of flats/dwelling converted in to flats	48	645	38	3,421	132	**4,283**
Total	**663**	**4,805**	**586**	**25,833**	**3,678**	

For context, the total number of each domestic property type for each fuel is displayed below in Table 8-8.

Table 8-8: Total number of each domestic property type using each heating fuel

Total number of domestic property types by each heating fuel						
Property Type	**Biomass**	**Electricity**	**LPG**	**Mains Gas**	**Oil**	**Total**
Block of flats	854	68,337	863	318,657	488	**389,199**
Detached house	12,390	42,755	15,626	376,582	123,924	**571,277**
End-terraced house	3,142	22,568	1,650	200,653	7,184	**235,197**

Flat in mixed use building	1,093	41,807	999	87,156	2,723	**133,778**
Large block of flats	1,254	59,410	319	90,708	1,470	**153,161**
Mid-terraced house	3,482	32,804	1,588	277,312	5,972	**321,158**
Semi-detached house	8,724	44,171	4,051	407,024	23,657	**487,627**
Small block of flats/dwelling converted in to flats	3,285	48,829	2,463	332,998	9,268	**396,843**
Total	**34,224**	**360,681**	**27,559**	**2,091,090**	**174,686**	

Table 8-9: Total heating demand for each non-domestic property per fuel type

Total Heating demand (GWh per year) per non-domestic property type and for each fuel type					
Property Type	**Electric**	**Mains Gas**	**Oil**	**Other (Biomass, Waste & Solid Fuel)**	**Total**
General Assembly	386	155	49	20	**609**
General Industrial, Storage or Distribution	134	407	504	15	**1,062**
Hotels	1,413	212	266	189	**2,081**
Non-residential Institutions	779	389	87	39	**1,295**
Offices and Workshops	1,404	741	259	55	**2,460**
Other	52	20	9	2	**84**
Residential Institutions and Spaces	381	156	51	25	**612**
Restaurants and Cafes	289	225	63	12	**590**
Retail and Financial Services	1,105	238	117	16	**1,475**
Total	**5,944**	**2,545**	**1,405**	**373**	

For context, the total number of each domestic property type for each fuel is displayed below in Table 8-10.

Table 8-10: Number of each non-domestic property type by each heating fuel

Total number of domestic property types by each heating fuel					
Property Type	**Electric**	**Mains Gas**	**Oil**	**Other (Biomass, Waste & Solid Fuel)**	**Total**
General Assembly	4,125	1,676	512	205	**6,518**
General Industrial, Storage or Distribution	1,785	5,500	6,722	210	**14,217**
Hotels	16,605	2,504	3,119	2,214	**24,442**
Non-residential Institutions	12,242	6,199	1,333	599	**20,373**
Offices and Workshops	37,796	20,144	6,896	1,477	**66,313**
Other	772	309	135	33	**1,249**
Residential Institutions and Spaces	3,451	1,434	457	220	**5,562**
Restaurants and Cafes	6,369	4,984	1,387	272	**13,012**
Retail and Financial Services	55,818	12,132	5791	785	**74,526**
Total	**138,963**	**54,882**	**26,352**	**6,015**	

8.1.6 Historical calculations

Data was provided to us by the Scottish House Condition Survey (SHCS) which contains historical data on Scottish domestic properties. Contact was made with representatives from the SHCS. The following historic data was provided on an annual basis:

- Total number of each building type that is heated by different fuel types
- For each specific fuel building type- percentage in each SAP band
- Percentage of fuel type using each heating technology

Due to the small sample size of the SHCS, for less commonly used fuels, the data was not of sufficient quality to produce historical results. Regression analysis was conducted on the data received from the SHCS. This analysis provides an indication of the correlation between two different values and creates a resulting R squared number (R^2). An R^2 figure of 100% would indicate a perfect correlation whilst R^2 values of less than 80% are considered low and the data is viewed as unreliable Due to the low sample size of the survey, especially when filtering for less commonly used fuels, much of the data was not robust enough to generate reliable figures. See Table 8-11 for the respective R^2 values generated regarding the number of properties in each fuel category from 2011-2021.

Table 8-11: R^2 Values for the SHCS data for different fuels

Fuel	R^2 Value
Mains Gas	96%
Electricity	82%
LPG	70%
Oil	70%
Solid Mineral Fuel	23%
Communal Heating Fuels	0%

For this reason, historical values were only calculated for electricity and gas heating fuels, with R^2 values greater than 80%. The regression analysis produced coefficients to be used in a linear line equation (y=mx+c). This was used to generate the historical figures. Without the linear regression there is significant and likely unrealistic yearly fluctuations in the SHCS data when it is broken down. For the HA model, the coefficients generated from the SHCS data were applied to the 2021 figures. These coefficients were then used to calculate the year-on-year difference. This process is also described in the Excel models.

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