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Expanding Scottish energy data – electricity demand

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1 Executive summary

1.1 Aims and approach

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. However, despite a high proportion of electricity generation coming directly from renewables (estimated at 98.6% in 2020[1]), both heating and transportation remain heavily reliant on direct burning of fossil fuels.

As set out in Scotland's energy strategy[2], 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 energy by 2030 (estimated at 25.4% in 2020[3]).

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:

- **Work package 1: Electricity use in properties –** Development of a methodology to determine an annual time series of electricity use for heating and for non-heating purposes for electrically heated properties
- **Work package 2: Electricity use for heat pumps –** Development of a methodology to determine an annual time series of electricity use by heat pumps in properties
- **Work package 3: Low-carbon energy use in transport –** Development of a methodology to determine an annual time series of low-carbon transport energy

[1] Source: Scottish Energy Statistics Hub (shinyapps.io)
[2] Source: The future of energy in Scotland: Scottish energy strategy - gov.scot (www.gov.scot)
[3] Source: Scottish Energy Statistics Hub (shinyapps.io)

use in Scotland, capturing electricity consumption of electric vehicles (EVs), electrified rail, hydrogen and electric buses and biofuels.

For each work package, the approach involved identifying the most appropriate sources of data available and producing a methodology to draw on this data to determine the time series information listed above.

Data sources used for work packages 1 and 2

- **Home Analytics (HA):** Dataset of over 2.7 million records, covering the Scottish housing stock. For this dataset, 57% of the information originates from Energy Performance Certificates (EPCs), while the remainder is modelled. This has been the primary dataset used for the modelling of domestic properties for this project and is used to produce present-day results regarding heat and electricity consumption in domestic electrically heated properties.
- **Non-Domestic Analytics (NDA) Database:** Dataset of over 226,000 non-domestic properties in Scotland. For this dataset, less than 15% of the properties contain data from non-domestic EPC records. The data for the remaining properties is modelled. This dataset has been used to produce present-day results regarding heat and electricity consumption in non-domestic electrically heated properties.
- **Scottish House Condition Survey (SHCS):** Results of this survey covering domestic properties are published annually. This survey is based on approximately 3,000 domestic properties. This dataset has been used to model the historical performance of domestic properties in Scotland. The most recently available data was for 2019, which was provided by the Scottish Government [1].

The key assumptions in the approach relate to:

- Estimates of how much (in degrees) and how long (in days) the external temperature is below a set temperature in each local authority area
- Estimates of how readily heat is lost from within a building to the outside when a temperature difference between the two exists. A heat loss coefficient can be assigned to different tiers based on the property type and their EPC rating
- The efficiency assigned to an average heat pump over a whole season (Seasonal Performance Factor).

Key data sources used for work package 3

- **Anonymised MOT data:** Data on annual mileages undertaken by motorcycles, cars and LGVs.
- **UK Department for Transport statistics:** Data on annual mileages for buses and HGVs.
- **Department for Transport Vehicle Licensing Statistics:** Data on the number of low-carbon vehicles registered in Scotland.
- **Energy data provided by different rail organisations:** Data on low-carbon energy use in the rail sector.

1.2 Findings

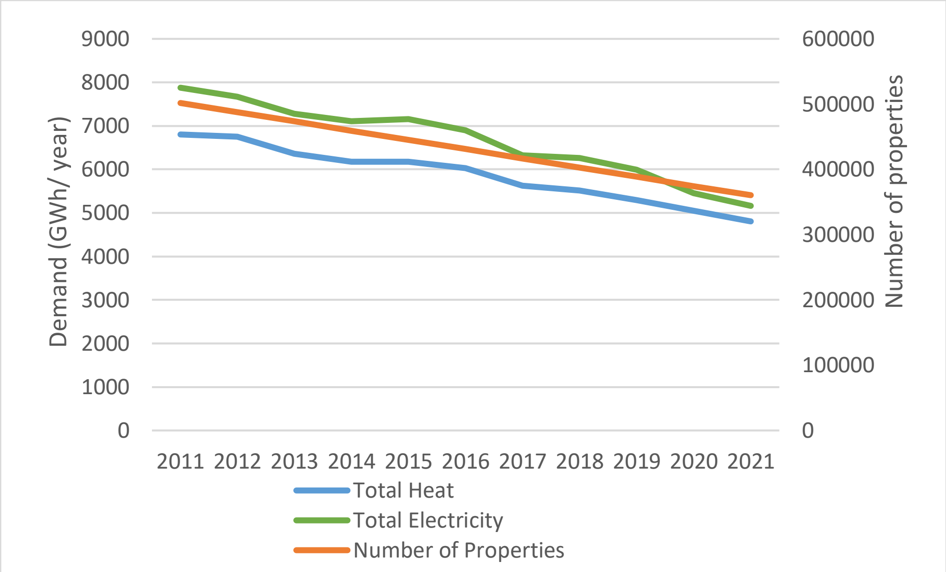
Electricity use in electrically heated properties

The annual heat demand in Gigawatt hours (GWh) for all domestic electrical heating across Scotland are presented in Figure 1-1 below. This includes heat technologies such as electric boilers, heat pumps, storage heaters and air heaters.[4] Data from HA

[4] Process heat (i.e. heat used in industrial processes) was not included as part of this analysis

was used to generate present-day results and was used in conjunction with data from the SHCS to generate historical results for the last ten years. This methodology is explained in further detail in Section 8.1.5.

Figure 1-1: Annual heat demand for all domestic electrical heating

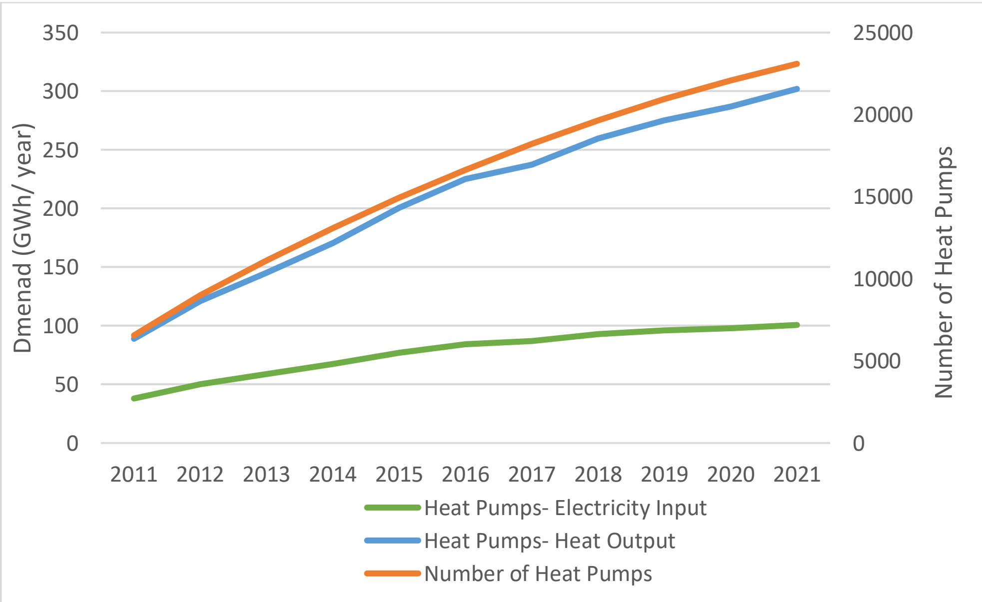


The modelling developed for this research illustrates that number of domestic properties in Scotland which are electrically heated is declining. Over the last decade, the overall energy efficiency of properties in Scotland has risen. Our analysis indicates that these two factors are contributing to an overall fall in electrical heat demand, as seen in Figure 1-1. Further details on the modelling approach are set out in Sections 4.1.1 and 8.2.5.

Domestic heat pump usage

In contrast, the total heat demand supplied by domestic heat pumps is increasing, as visible in Figure 1-2.

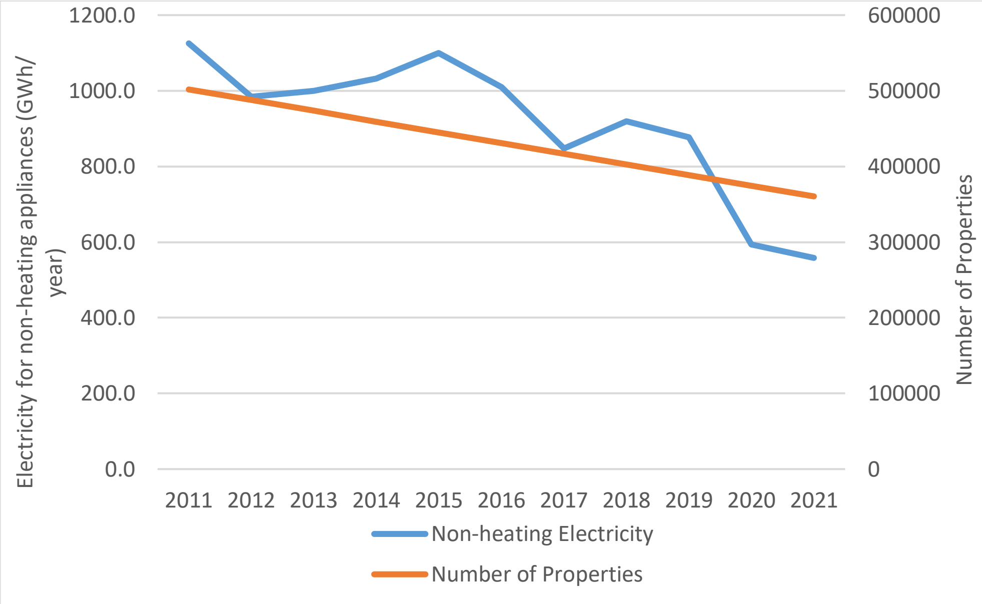
Figure 1-2: Demand from domestic heat pumps



For both Figure 1-1 and Figure 1-2, the linear trend shown for "number of properties" and 'numbers of heat pumps' is a result of them being derived through regression analysis of data provided by the SHCS.

For domestic electrically heated properties, the non-heating electrical demand was also modelled. Figure 1-3 shows that non-heating electrical demand fell from 1126GWh in 2011 to 558GWh in 2020. This is due to the total number of electrically heated properties falling, as well as the average electrical demand for domestic properties decreasing, from an average of 4200kWh in 2010 to 3600kWh in 2019 [2].

Figure 1-3: Non-heating demand for electrically heated domestic properties



There is currently no equivalent to the SHCS for non-domestic properties. As a result, it was not possible to generate historical results of heat and electricity consumption of electrically heated non-domestic properties. Data from the NDA database was utilised to generate present-day figures for electrically heated properties. Values for heating demand, the resultant electricity demand and the non-heating demand for these non-domestic properties have been generated - see Table 1-1.

Table 1-1: 2021 figures for non-domestic properties

Year		Heat Pump	Other Electric Heating	Non-Heating	Total
2021	Electricity consumed	256 GWh	5,174 GWh	1,658 GWh	7,088 GWh
	Heat generated	767 GWh	5,174 GWh	N/A	5,941 GWh

Transport energy usage

This study carried out a high-level analysis of the transport energy consumption from low-carbon road and rail transport. MOT data and Department for Transport statistics [9] provided a source for the number of low-carbon Ultra Low Emission Vehicles (ULEVs)[5] and their average mileages. Additionally, the average energy consumption across the vehicle types was obtained, which allowed the total energy consumption of each vehicle class to be calculated. Table 1-2 presents the number of low-carbon vehicles and their total energy consumption in 2020.

Table 1-2: Road transport number of low-carbon vehicles and total energy consumption 2020

	Motorcycles	Cars (BEV)	Cars (PHEV)	LGV (BEV)	LGV (PHEV)	HGV	Buses
Number of vehicles	162	10,551	9,212	754	45	9	35
Total energy consumption (GWh)	0.01	22.12	5.79	3.46	0.06	0.5	4.22

All the electrified rail transport in Scotland was considered to be low carbon. Data about the annual energy consumption was directly obtained from Network Rail and the two local rail transport operators, Edinburgh Trams and Glasgow Subway. Table 1-3 presents the total energy consumption results.

Table 1-3: Total energy consumption of low-carbon rail transport in Scotland

	2016	2017	2018	2019	2020
Network Rail	Not available			351 GWh	279 GWh
Edinburgh Trams	4.18 GWh	5.50 GWh	5.70 GWh	5.66 GWh	4.23 GWh
Glasgow Subway	N/A	N/A	6.84 GWh	6.73 GWh	5.77 GWh

1.3 Recommendations

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

- Close engagement with the Energy Saving Trust (which manages the HA and NDA dataset) to establish how frequently the datasets are updated and update the model accordingly to reflect changes in the building stock.
- 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 NDA Database. This would increase the accuracy and reliability of the data that the model draws on. This may come at a significant cost to implement, but it is recommended that the Scottish Government explores mechanisms to improve the reliability of recorded EPC data.
- It is recommended that the degree days and heat loss coefficient tiers are reviewed every five years. It is highly unlikely that changes in building stock will change the assumptions by a significant margin over short timescales.
- Installation of heat pumps is set to become more common, and the efficiency of heat pumps is likely to increase. We recommend that the Scottish Government liaises with the two major network operators in Scotland (Scottish Power Energy Networks and Scottish & Southern Electricity Networks) which are likely to be well placed to provide information on the number of heat pumps connected to the network. In addition, it may be worth exploring with the Microgeneration

[5] Ultra Low Emission Vehicles (ULEVs) are defined as vehicles with reported tailpipe CO_2 emissions of less than 75 g/km

Certification Scheme (MCS) whether it is able to provide reliable and updated data on heat pump installation numbers and efficiencies.

- More data is required on the heat demand and energy efficiency of non-domestic properties. This may be achieved over time as the NDA Database is updated with non-domestic EPC records.

Contents

2 Introduction

2.1 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. It was estimated that in 2020, the equivalent of 98.6% of Scotland's gross electricity consumption was from renewable sources of energy [3]. Despite a high proportion of electricity generation coming directly from renewables, both heating and transportation 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 energy by 2030. Having 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.

Ricardo Energy & Environment (Ricardo) was commissioned by ClimateXChange on behalf of the Scottish Government to develop new and improved methodologies for collecting and assessing energy data in Scotland. This will enable an improved detailed understanding of energy data across Scotland, relating to electricity demand, heat pump demand and transport energy demand. The methodologies are designed to be repeatable by the Scottish Government and can be developed further when more energy data becomes publicly available, which will enable a stronger evidence base. The opportunities for improved data collection are detailed as part of this project.

This report provides the results of the exercise undertaken which will enable the Scottish Government to track how Scotland's energy performance is changing by using the new and improved methodologies, as well as improving them further when more data becomes readily available.

2.2 Requirements of the project

The project provides methodologies to estimate the energy consumption in three key areas:

- **Work package 1: Electricity use in properties -** An annual time series of electricity use for heating and for non-heating purposes for electrically heated properties
- **Work package 2: Electricity use for heat pumps -** An annual time series of electricity use by heat pumps in properties
- **Work package 3: Low-carbon energy use in transport -** An annual time series of low-carbon transport energy use in Scotland

Due to the similarities and crossovers between work packages 1 and 2, a single proposed methodology that addresses both aspects has been developed.

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 and processed in excel to produce datasets to track the energy consumptions in the building and transport sectors in Scotland.

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 derive estimates of electricity consumption in domestic and non-domestic buildings alongside low-carbon transport energy use

The following sections discuss the data sources collected for the analysis and the methodology developed to answer the key project questions for each subtask.

3.1 Electrically heated properties

The aim of work package 1 was to develop a repeatable methodology to estimate the electricity use for heating and non-heating purposes for electrically heated properties, where the primary heating fuel is electricity. The aim of work package 2 was to estimate the electricity consumption of heat pumps in both domestic and non-domestic buildings. This section explains the methodology developed to answer the key project questions for work packages 1 and 2.

3.1.1 Data sources for electrically heated properties

The first step was to identify existing data sources that can provide information about electricity demand data with sufficient granularity. Data sources that were selected for the analysis are as follows:

Table 3-1: List of data sources considered to estimate the electricity use in electrically heated properties

Data sources reviewed	Relevance to the project
Home Analytics (HA)	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 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.

Data sources reviewed	Relevance to the project
	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. 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.
National Energy Efficiency Data Framework (NEED)	The Department for Business, Energy & Industrial Strategy (BEIS) publish this dataset annually. It reports on average and total gas / electricity consumption for different domestic and non-domestic property types. The majority of the data used to calculate these figures is from meter-data, with the remainder coming from other sources such as the Ordnance Survey and Ofgem. The relevant information from this dataset for this project is the average electricity consumption for different types of domestic and non-domestic properties. This information was used to estimate electricity consumption for non-heating purposes.

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. The modelling process adopted in HA and NDA involved the use of multinomial logistic regression models. These models use a variety of address-level predictors such as property type, age, tenure, urban/rural classification, Index of Multiple Deprivation (IMD) decile 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: Variables from HA that have been utilised in the development of the model

Field Name	Description
Local authority (LA)	This is the local authority area that each property resides within
Property type	The property type of each domestic building, the categories are: • 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 large tower block.
Total floor area estimate (m^2)	An estimate of the property’s floor area, used to calculate the Heat Transfer Coefficient for each property type
Main fuel type	The primary fuel type used to heat the property. For the purpose of this project, this was filtered to focus on electrically heated properties
Standard Assessment Procedure rating band	The energy efficiency 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 total heat demand
Main heating technology	The is the main heating technology used for each building type, these include: • Air heater • Boiler • Heat Pump • Room heater • Other
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: Variables from NDA that have been utilised in the development of the model

Field Name	Description
Local authority (LA)	This is the local authority area that each property resides within
Property Type	The property type of each non-domestic building, the categories are: • Restaurants and Cafes • Retail and Financial Services- A property serving as a shop/ financial service such as a bank • General Industrial, Storage or Distribution- Properties such as warehouses and depots • Offices and Workshops- Properties included in this category are offices and small-scale manufacturing premises • Hotels • Residential Institutions and Spaces- Properties in this category include care homes, hospitals, and prisons • General Assembly- Properties such as factories • Non-residential Institutions- Properties within this category include museums, libraries, and law courts • Other- Any non-domestic property that can not be categorised into the classifications discussed above
Total floor area estimate (m^2)	An estimate of the property's floor area, used to calculate the Heat Transfer Coefficient for each property type
Main fuel type	The primary fuel type used to heat the property. For the purpose of this project, this was filtered to focus on electrically heated properties
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, space and water heating were split out as separate variables, in HA they are combined into one variable.
Main heating technology	The is the main heating technology used for each building type, these include: • Air heater • Boiler • Heat Pump • Room heater • Other

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, however they arrive at it via different methods.

Table 3-4 provides a comparison between the two data sets to highlight key differentiating points.

Table 3-4: Comparison between HA and the SHCS

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 3000 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 rental property • 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 and can be split by local authority. • SHCS only provides data based on urban/ rural split.
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. • HA is a dataset provided by an outside contractor; it is not necessarily updated annually.

Out of the two datasets, HA is far more granular, with much greater detail regarding property location and property characteristics. However, the data in HA is skewed, due to its dependency on EPC certificates. Properties in urban areas, new-builds and rental properties are all more likely to have had EPCs issued than the average property. These property types are likely to be being overrepresented in the dataset. The SHCS is arguably more representative, however the main disadvantage of this survey is the small sample size. Due to the small sample size, made smaller when filtering for only electrically heated properties, year-on-year results for specific property types could fluctuate significantly, likely more than they do in 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.

Due to the significant variation between the methodologies used to compile the datasets, the figures generated by each dataset are different. A major difference identified during the completion of this project is that the SHCS identifies approximately 275,000 electrically heated domestic properties in Scotland, whereas HA contains approximately 360,000 such properties. The discrepancy in the raw figures that are input into the model will lead to a discrepancy in the results generated regarding heat and electricity consumption. As a result of the higher granularity of HA this dataset is used 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 4.1.

3.1.2 Methodology development

Estimating electricity consumption to meet the building heating requirements depends on two 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, floor area, the energy efficiency of the building and the location
- **Heating technology installed:** The efficiency of different electric heating technologies varies depending on the technology installed in the building

Our approach to calculating the total heating demand and the corresponding electricity demand for heating purposes of a property involved carrying out the following steps and calculations:

- **Calculating heating degree days:** This is the measure of how much (in degrees) and how long (in days) the external temperature is below a set temperature [4]. 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 hourly outside temperature was collected from Met Office stations across every local authority area in Scotland. Using a sensible base temperature of 15.5°C, the difference between the indoor and outdoor temperature can be estimated hourly and summed to predict the 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 [5].
- **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.
- **Efficiency of electric heating technology:** The efficiency of electric heating technologies varies across all technology types. For example, standard resistance heaters convert one kWh of electricity into one kWh of heat. This means that fulfilling a significant heating demand requires an equally significant amount of electricity consumption. In contrast, heat pumps have a higher conversion rate which varies across the different seasons. The Coefficient of

Performance (COP) is the ratio of heat energy delivered compared to the amount of electrical energy that is required. There are two methods to measure the COP of a heat pump. The first is instantaneous COP, which is the heat pumps efficiency at a specific period in time. The instantaneous COP will vary across the seasons, with a lower COP in the winter months. This is because as the input temperature reduces in the winter months, the heat pump has to work harder to extract heat from it and has to draw more electrical energy from the grid to heat the property up to the desired temperature. The second method of measuring COP is Seasonal COP (also known as the Seasonal Performance Factor (SPF)). SPF represents the average COP of a heat pump over the full heating season. This project focused on estimating a sensible SPF in order to estimate electricity consumed by a heat pump throughout the year.

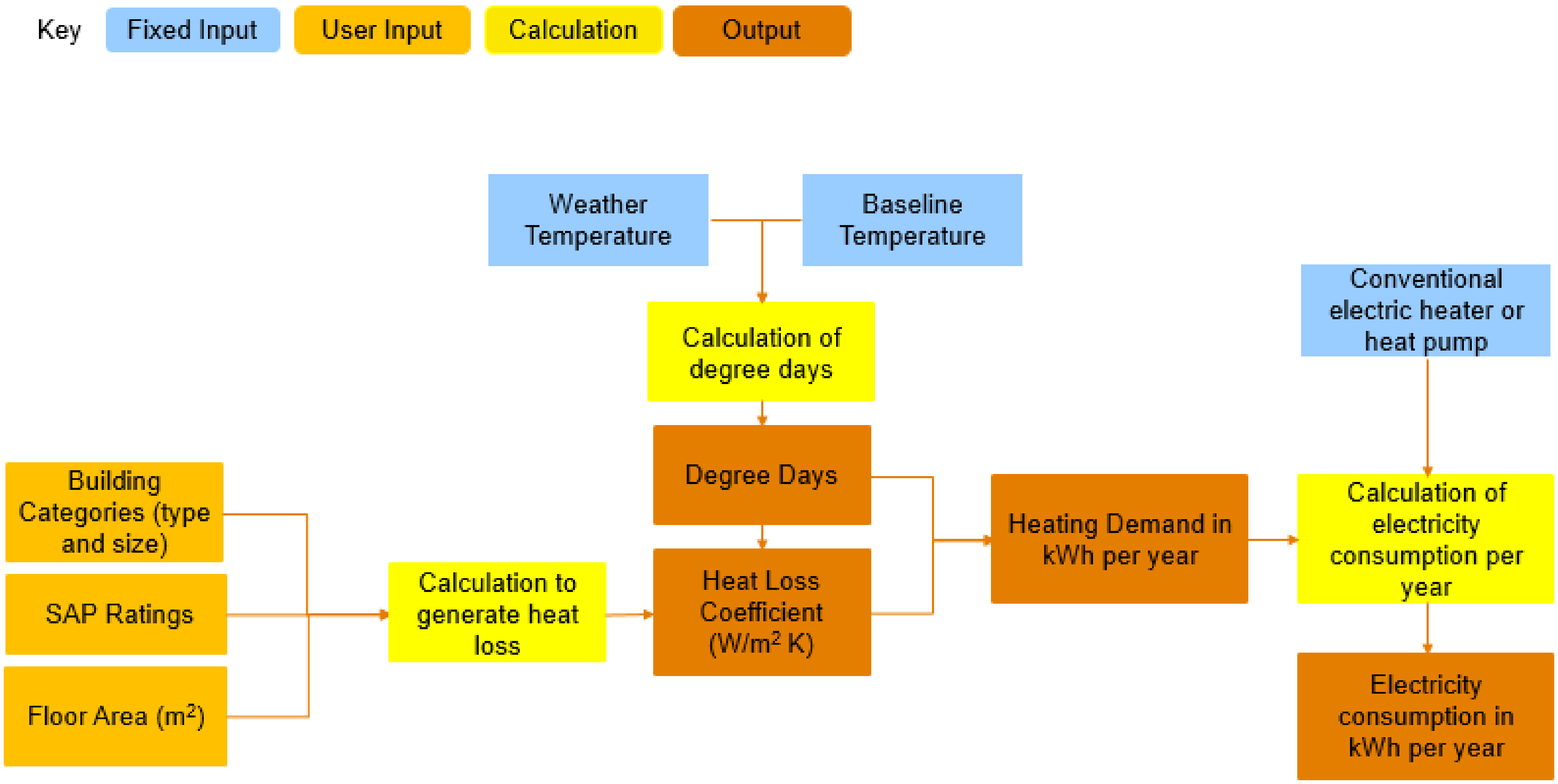
- **Calculating total electricity consumption:** Using the total heat demand estimated above for each property type in the dataset along with the efficiency of the electric heating technology (standard electric heaters or heat pumps) results in the estimation of the corresponding electricity consumption required in the building. The total heat demand divided by the efficiency of the electric heating technology generates the electric consumption, which is imported from the grid. This was estimated on a property-by-property basis using the assumptions of heat loss coefficient from the different tiers and subsequently added together to predict a national electricity consumption number.

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. This is described in more detail in Appendix 2.

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 electrically heated properties has changed, split by property type, SAP band and heating technology over the years. The heat and electricity demand calculated for the present-day situation was extrapolated using the historical trends presented by the SHCS to generate annual time series figures. This methodology is explained in greater detail in Appendix 8.2.5. Equivalent SHCS data for non-domestic properties was not available and therefore, generation of historical trends for non-domestic properties was not possible.

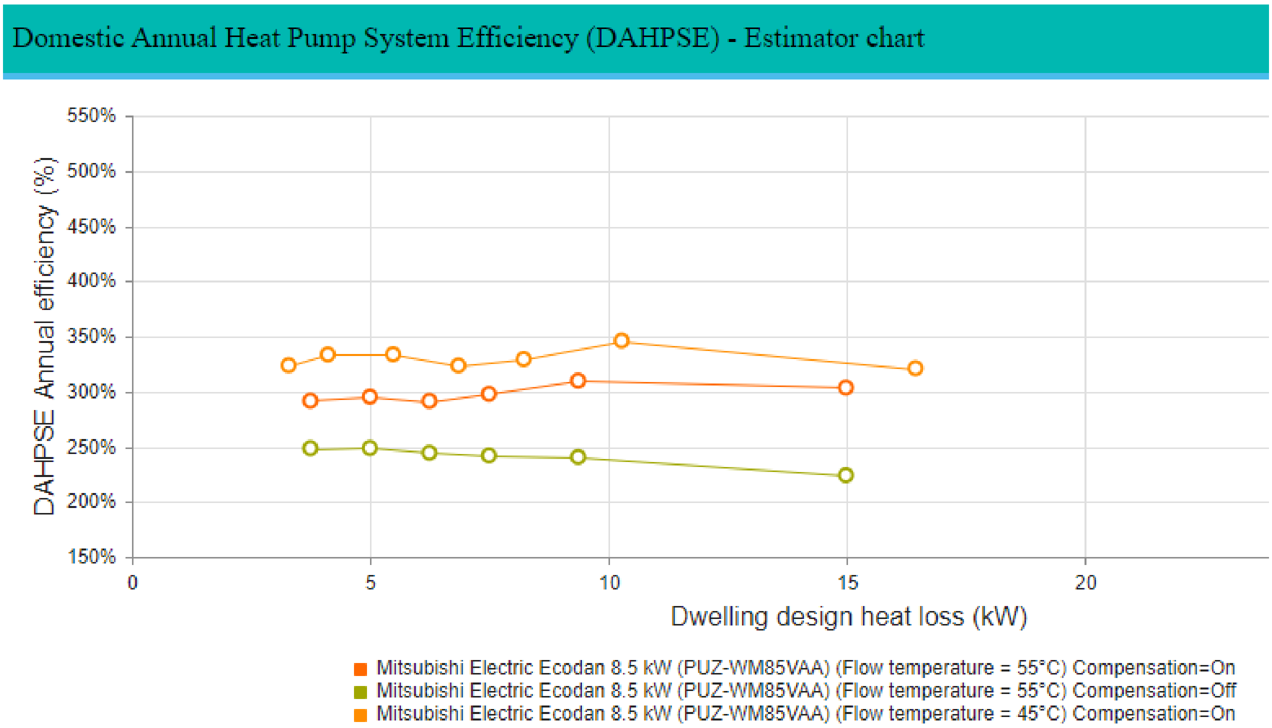
Figure 3-1: Flowchart showing the methodology deployed to estimate total electricity consumption in electrically heated properties for individual properties



A SPF was estimated using information provided from the Domestic Annual Heat Pump System Efficiency (DAHPSE) Estimator website [6]. The website contains information on typical domestic heat pump efficiencies for different heat pump manufacturers and how this varies with dwelling heat loss, design flow temperature and the presence of weather compensation.

Figure 3-2 below shows an example of the spread in heat pump efficiency with respect to the dwelling design heat loss when the design temperature and weather compensation variables are varied. The results show a typical spread in heat pump efficiency from 2.5 to 3.5. For this reason, an average SPF of 3 was deemed to be a reasonable assumption to make for different heat pump technology types.

Figure 3-2: Domestic Annual Heat Pump Efficiency estimations for different heat pump types



In order to generate annual time series estimations of electricity consumption, the change in the SPF over time needs to be taken into account. Historical SPFs are provided in Table *3-5*.

Table 3-5: Results of a phase 1 and phase 2 trial conducted by the EST from 2009 to 2012 into estimations of heat pump efficiency [7]

Year of study	Sample of ASHPs	SPF Range
2009 – 10	22	1.2 – 2.2
2011 – 12	17	2.0 – 3.7

An average SPF in 2010 was determined from the EST results. Using an average SPF of 3 for the year 2021, the SPF was extrapolated for the years in between 2010 and 2021. This allows historical average heat pump efficiencies to be accounted for in the analysis; however, this does not provide a clear picture of how heat pump efficiency numbers have changed over the years as the data that records this information is not readily available. Despite the limited data available on historical heat pump efficiencies, the numbers provided in Table 3-5 are deemed sufficient for this project.

3.2 Low-carbon transport

Transport is a major contributor to GHG emissions in Scotland. In 2019, 37% of the total emissions in the country were generated by the transport sector, and 69% of the transport emissions came from road vehicles [8]. Electrification and transition to sustainable fuels like hydrogen has the potential to bring about a major cut in these emissions.

In this work we aimed to quantify the energy use of low-carbon vehicles, which were split into the following categories:

- Motorcycles
- Cars
- Light goods vehicles (LGV)
- Heavy goods vehicles (HGV)
- Buses and coaches
- Rail transport (trains, trams and underground).

Additionally, this analysis presents historic data for the energy consumption of these vehicle categories and will allow future figures to be tracked on an annual basis.

3.2.1 Data sources for the transport analysis

Table 3-6 presents the data sources used in the transport analysis.

Table 3-6: Data sources for the transport analysis

Data sources reviewed	Relevance to the project
Department for Transport Vehicle Licensing Statistics	Statistics on number of low-carbon vehicles registered in Scotland across different classes of road transport ranging from motorcycles to buses and HGVs. This was provided from Transport Scotland on request to the Department for Transport to extract Scottish figures from statistics which are published at the UK level.
UK Department for Transport statistics	Typical annual mileages for buses and HGV [9] [10] [11].
Anonymised MOT data	Dataset that allows the annual mileages to be extracted for motorcycles, cars and LGVs [12].
Network Rail	Total energy consumption data of the electrified rail infrastructure in Scotland was provided on request.
Edinburgh Trams	Total energy consumption for traction from the operations of Edinburgh Trams. Provided on request.
Glasgow Subway	Total energy consumption for traction from the operations of Glasgow Subway. Provided on request.
ScotRail	Total energy consumption of electrified rail along with total distance for all train journeys travelled broken down over a calendar year.

3.2.2 Methodology

In this section, we present the different methodologies we adopted for road and rail transport.

Road transport

The data available on low-carbon road vehicle numbers provides annual time series for registered low-carbon vehicles from 2010 until present day. This data is publicly available and can be updated on a regular basis.

To establish the annual mileages for motorcycles, cars and LGVs, publicly available anonymised MOT data was used. The MOT data provides information about the vehicle class and mileage plus a unique identifier which allows the difference in mileage between two MOTs for each individual vehicle to be calculated. The vehicle classes in the MOT data are as follows:

- Cat 1 - small motorcycles
- Cat 2 - motorcycles
- Cat 3 - three-wheelers
- Cat 4 - cars
- Cat 5 – Private passenger vans
- Cat 7 – LGV

Three-wheelers (Cat 3) were not included in the analysis as they do not appear in the statistics for low-carbon vehicles, and they represent a very small proportion of all vehicles (7,246 out of more than 40 million MOT entries).

Private passenger vans (Cat 5) were also excluded in the analysis as there is no corresponding category in the low-carbon vehicle statistics.

A script was developed in Python to extract the anonymised MOT data, perform data quality check to remove invalid data, and to develop a process for estimating annual mileages for each classification of vehicle.

Using each vehicle's identifier, the difference in odometer readings was calculated between 2020 and 2019, which allowed the average annual mileage for each vehicle class to be calculated. To arrive at the average mileage for motorcycles, an average of the results for small motorcycles (Cat 1) and motorcycles (Cat 2) was taken. Recognising that this year was an outlier due to the COVID-19 pandemic and the average mileage is lower than typical, a further iteration of the analysis was run for the difference in odometer readings between 2019 and 2018 to populate annual mileages in the historic analysis.

For HGVs, buses and coaches we used UK Department for Transport statistics to obtain average annual mileages. The data provides total number of vehicles in Scotland plus total annual vehicle miles, from which the average mileage was calculated.

Typical energy consumption for the different classes of vehicles and types of propulsion were established based on average values or energy consumption of the dominant vehicles in each class. For electric vehicles (battery and fuel cell) the values are presented in watt hour per mile (Wh/mile) accounting for efficiency penalties and are subsequently multiplied by the number of vehicles in each class and their typical annual mileage to arrive at the total energy demand. It should be noted that as the characteristics of vehicles change, the energy consumption figures should be updated. It was assumed that all HGVs, buses and coaches are electric, as the available data does not provide a breakdown by storage system. There are a small number of hydrogen buses in Scotland that are excluded by this analysis, however, provisions have been made in our calculation tool to input hydrogen HGVs, buses and coaches once more detailed statistics become available. The hydrogen calculations use the same energy requirements, but they also account for the larger efficiency penalty that arises from the fuel cell system. Data was requested on biofuel uptake in Scotland from Transport Scotland, but this information isn't currently available.

The analysis of plug-in hybrid electric vehicles was built upon utility factors of the electric motors and energy consumption figures from electric vehicles. Firstly, the utility factor, which is the proportion of distance covered using the electric motor, was estimated for plug-in hybrids. The figures under test conditions suggest that the electric propulsion system has a significant contribution, with average utility factors of between 60% and 70%. However, large scale studies found that the actual utility factor of plug-in hybrids is significantly lower – between 20% and 37% [13]. This is typically due to overreliance on the internal combustion engine (ICE) and infrequent charging. These figures are corroborated by another study that found similar results [14] . Therefore, this analysis uses a utility factor of 30% that is representative of real-world performance rather than utility factors under test conditions (note that a representative value was selected rather than a calculated average, so an expected level of uncertainty is reflected).

In terms of energy consumption figures we identified significant variation between the most popular models of PHEV, however, to a large extent they are comparable with battery electric vehicles. Therefore, the same energy consumption figure would be used for the PHEV analysis. The total energy consumption was found by multiplying the utility factor by the energy consumption, which are then multiplied by the average annual mileage and the number of PHEVs.

It should be noted that mild hybrids[6] were excluded from this analysis as all the energy delivered by the electric propulsion system was charged using the vehicle's ICE. The benefits in this type of vehicle result from charging occurring during times when the ICE is working around optimal efficiency, which offsets usage of the ICE at start-stop traffic for example. As a result, the actual reduction in fuel consumption is difficult to quantify as no large-scale real-world studies could be obtained.

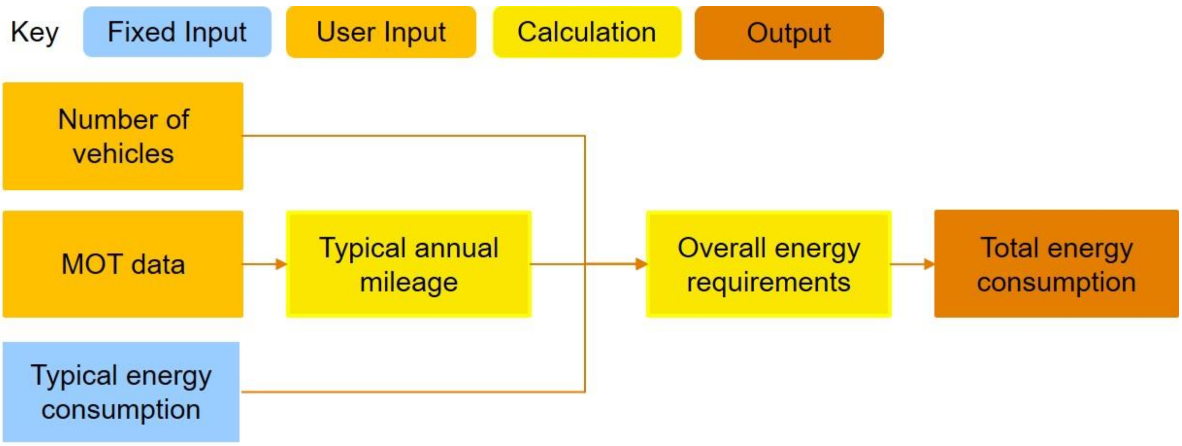
Range extender[7] electric vehicles, which form about 1% of the total number cars and LGVs, were included in the analysis of BEVs. This segment is dominated by the BMW i3 (86%), which is a small city car with a large capacity battery and, therefore, it is expected that its usage pattern will be similar to BEVs [15]. Again, provisions have been made to separate out the analysis of range extender vehicles should their overall proportion become larger and more reliable figures for their utility factors become available.

The category of "Other vehicles" presented in the Department for Transport data covers vehicles like forklifts, waste collection vehicles, ambulances, etc. and the total number of vehicles in this category represents 0.7% of the total low-carbon vehicles in Scotland. There is no available data that provides a breakdown by type and there is no available method to accurately estimate the annual mileages and energy consumption across the category. Therefore, "Other vehicles" was excluded from the analysis. Figure *3-3* presents a flow chart that depicts the steps in this analysis.

[6] Mild hybrids are vehicles which only charge the battery by using the internal combustion engine (and in some cases regenerative breaking). These vehicles have no option to charge by plugging into electric charger. Typically these vehicles use the electric powertrain mostly in conjunction with the internal combustion engine to achieve efficiency gains.

[7] Range extender EVs use the electric power train for propulsion and have the option to plug in. They are also equipped with an internal combustion engine that can be used purely for battery charging when necessary.

Figure 3-3: Road transport analysis methodology flow chart



Rail transport

The analysis of the energy consumption from low-carbon rail transport in Scotland was conducted using three sources of data – total energy consumption from Network Rail, Edinburgh Trams and Strathclyde Passenger Transport Authority data into the Glasgow Subway. The data sources are not publicly available and need to be requested annually from the respective organisations for up-to-date figures.

The data from Network Rail covers the traction demand from all of the electrified railways in the country and, therefore, it covers all of the rail operators.

The data provided by ScotRail provides total traction demand data along with train journeys in miles for all trains that are owned by ScotRail, therefore covering the majority of all rail journeys in Scotland.

Edinburgh Trams and Glasgow Subway are the two other rail transport networks operating in Scotland. The breakdown of the energy consumption data, showing energy demand at half-hourly intervals for each substation, was obtained for both rail networks.

It was not possible to obtain total mileages of electrified rail journeys for the whole of Scotland. Only total mileages were obtained from ScotRail, which is the largest train operating company in Scotland. Data on the small train operators' total mileage was not available when requested after speaking to Network Rail.

4 Key findings

4.1 Electricity demand

The accompanying spreadsheet tool calculates heating consumption figures for both domestic and non-domestic properties. In addition, we calculated the non-heating electricity demand in electrically heated properties.

4.1.1 Electricity usage in electrically heated domestic properties

Data from HA has been utilised to generate heat demand figures for 2021. The non-heating electrical demand has been calculated using data from the NEED-UK database. There are approximately 360,000 electrically heated domestic properties in Scotland, based on the data in HA, and an overview of the electricity consumption figures for 2021 is presented in Table 4-1.

Table 4-1: Total domestic heat and electricity consumption in electrically heated properties for 2021

Year		Heat Pump	Other Electric Heating	Non-Heating	Total
2021	Electricity consumed	101 GWh	4,503 GWh	558 GWh	5,169 GWh
	Heat generated	302 GWh	4,503 GWh	N/A	4,805 GWh

The heat demand has been separated into the heat demand from heat pumps and the heat demand from other electrical heating technologies. A more in-depth view of the heat demand for 2021 is available in **Error! Reference source not found.** below by property type and SAP band.

Table 4-2: Total domestic heat demand for 2021, split by property type and SAP band

Heat Demand Total (GWh/ year)	A-B	C	D	E	F-G	Total
Detached house	31 GWh	81 GWh	230 GWh	263 GWh	383 GWh	**988 GWh**
Semi-detached house	12 GWh	70 GWh	247 GWh	250 GWh	199 GWh	**778 GWh**
Block of flats	15 GWh	143 GWh	252 GWh	162 GWh	85 GWh	**657 GWh**
Small block of flats/dwelling converted into flats	10 GWh	93 GWh	219 GWh	186 GWh	136 GWh	**644 GWh**
Mid-terraced house	5 GWh	47 GWh	176 GWh	175 GWh	109 GWh	**512 GWh**
Flat in mixed use building	16 GWh	93 GWh	140 GWh	125 GWh	89 GWh	**463 GWh**
Large block of flats	36 GWh	153 GWh	120 GWh	48 GWh	31 GWh	**388 GWh**
End-terraced house	5 GWh	29 GWh	117 GWh	125 GWh	100 GWh	**376 GWh**
Total	**130 GWh**	**709 GWh**	**1,501 GWh**	**1,334 GWh**	**1,132 GWh**	

Approximately 83% of the heat demand generated by Scottish properties at present is from properties within Band D, Band E or Band F-G (see details of the breakdown in Table 4-3).

Table 4-3: Percentage of 2021 heat demand from properties within each SAP band

SAP Band	A-B	C	D	E	F-G
Percentage of Total Heat Demand	3%	15%	31%	28%	24%

Percentage of Total Properties	6%	25%	33%	21%	15%

Unsurprisingly, the larger property types such as detached houses and semi-detached houses, seen in Table 4-4, constitute the largest share of the heat demand (combined demand is 37% of the total) for 2021, despite accounting for only 24% of the number of properties.

Table 4-4: Percentage of heat demand for 2021 for each property type

Property Type	Percentage of Heat Demand
Detached house	21%
Semi-detached house	16%
Block of flats	14%
Small block of flats/dwelling converted in to flats	13%
Mid-terraced house	11%
Flat in mixed use building	10%
Large block of flats	8%
End-terraced house	8%

The average annual heat demand for each of these property types is displayed in Figure 4-1. The average heat demand for all electrically heated property types is approximately 13,300 kWh from the estimations undertaken in HA.

Figure 4-1: Average heat demand for different domestic property types

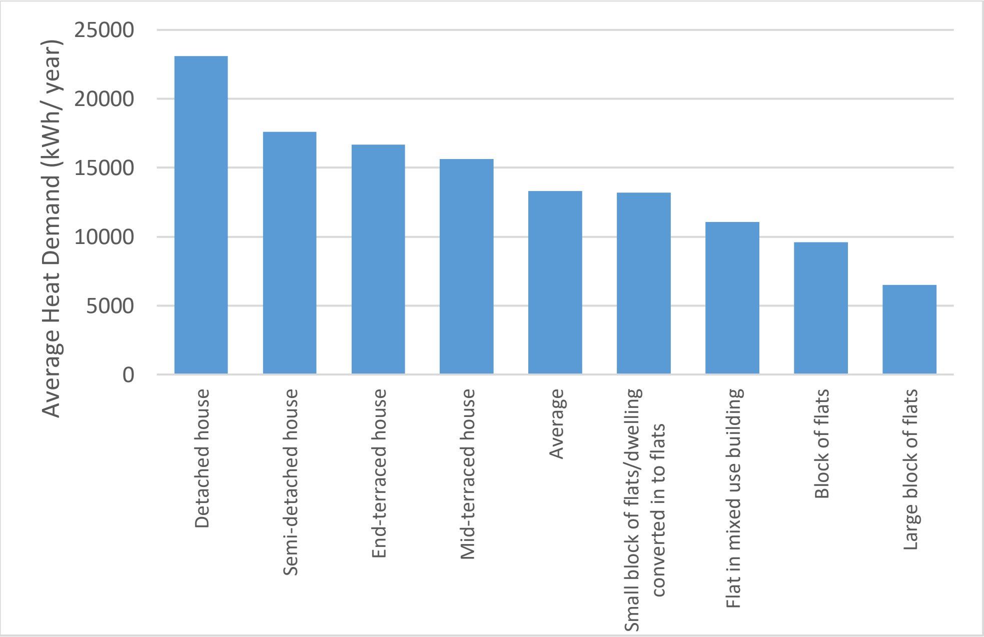


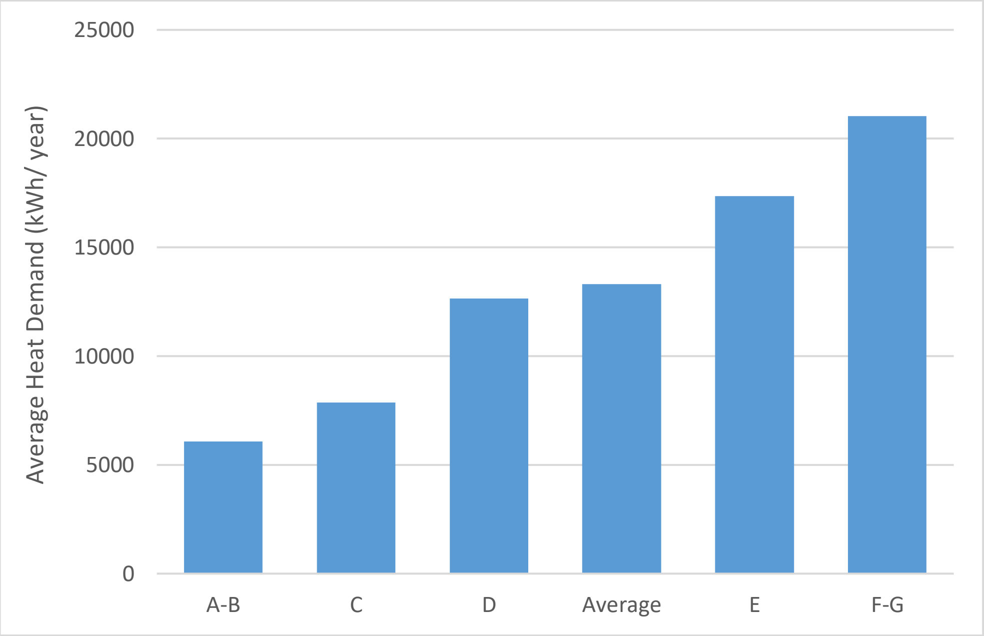
Figure 4-1 highlights that detached houses and semi-detached houses have the largest heat demands on average. Inversely, smaller properties, in large blocks of flats, have the smallest heat demands. Table 4-5 highlights that, generally, electrically heated properties in Scotland tend to be less efficient than the average domestic property. As a result, the average heat demand for electrically heated properties is likely to be greater than the overall average demand.

Table 4-5: Percentage of domestic properties in each SAP band- using electricity/ other fuel for heating

SAP Band	A-B	C	D	E	F-G
Electricity	6%	25%	33%	21%	15%
All Fuels	8%	37%	36%	13%	6%

Figure 4-2 displays the average heat demand for each domestic SAP band, based on the data provided in HA.

Figure 4-2: Average heat demand for properties within each SAP band



Data from the SHCS has been used, in conjunction with the HA database, to generate historical heat and electrical consumption figures.

Table 4-6 shows an example of these historic figures for 2011.

The data from the SHCS provides different SAP bands and different property types to the data in HA. As discussed in Section 3 (further detail in Appendix 2)., HA was deemed to be the more reliable data set, so SHCS figures were used to extract the general trend for number of properties under each type and SAP band and applied to data from HA.

Similarly to Table 4-2, the heat demand for 2011 has been split up by property type and SAP band, shown in Table 4-7.

Table 4-6: Total domestic heat and electricity consumption in electrically heated properties for 2011

Year	Energy source	Heat Pump	Other Electric Heating	Non-Heating	Total
2011	Electricity consumed	94 GWh	7,073 GWh	1,126 GWh	**8,239 GWh**
	Heat generated	40 GWh	7,073 GWh	N/A	**7,167 GWh**

Table 4-7: Total heat demand in Scotland for 2011, split by property type and SAP band

2011	C Plus	D	E, F, G
Detached	8 GWh	207 GWh	1,175 GWh
Semi-detached	35 GWh	386 GWh	766 GWh
Terraced	37 GWh	702 GWh	702 GWh
Tenement	557 GWh	682 GWh	1,108 GWh
Other flats	201 GWh	318 GWh	283 GWh
Total	**838 GWh**	**2,295 GWh**	**4,034 GWh**

According to the model used, the number of electrically heated properties has decreased from approximately 516,000 properties in 2011 to approximately 360,000 in 2021. This equates to a total reduction of 40%, with an average of 3% each year. This modelling process involved applying the relative year-on-year changes in the number of electrically heated properties recorded in the SHCS to the present-day number of electrically heated properties in HA. This is necessary as a result of a large discrepancy between the number of electrically heated properties in HA and the SHCS. Using raw SHCS data to produce the historical results alongside input from HA for the present day would result in a very large, and unrealistic, increase in the number of electrically heated properties from 2019 (SHCS) to 2021 (HA). A separate model has been developed that fits a linear regression to the raw SHCS data instead (details are set out in Section 4.1.5 and explained further in Section 8.2.5) that does not utilise this scaling-up approach.

There is significant variation in the year-on-year change in the number of electrically heated properties in the raw SHCS data. This ranges from a decrease of approximately 48,000 properties from 2017-2018, to an increase of approximately 26,000 from 2016-2017. Linear regression has been used to generate an overall trend for the number of electrically heated properties from the data which records considerable year-on-year fluctuations.

The decline in heat demand resulting from the reduced numbers of electrically heated properties and increased heat efficiency of domestic properties is presented in Figure 4-3.

Figure 4-3: Annual heat and electricity demand in Scottish electrically heated domestic properties

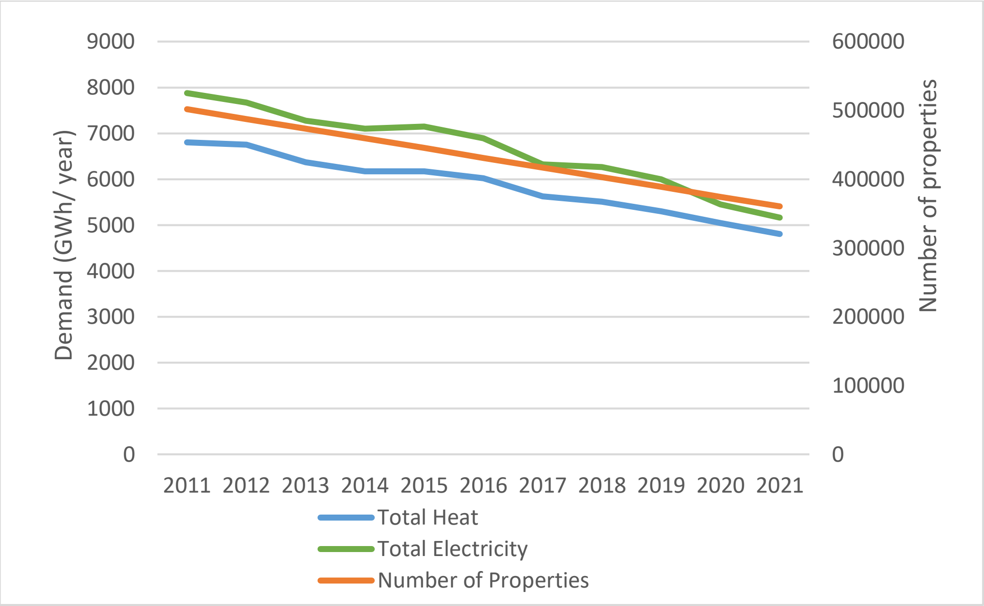
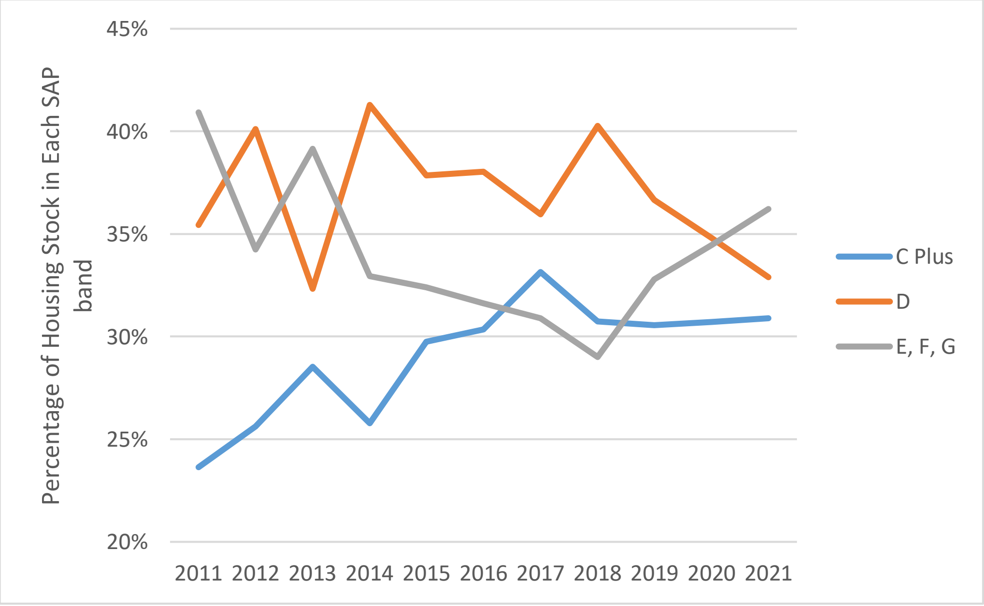


Figure 4-4 illustrates how the percentage of Scottish electrically heated properties in each SAP band has changed from 2011- 2021.

Figure 4-4: Proportion of properties within each SAP band

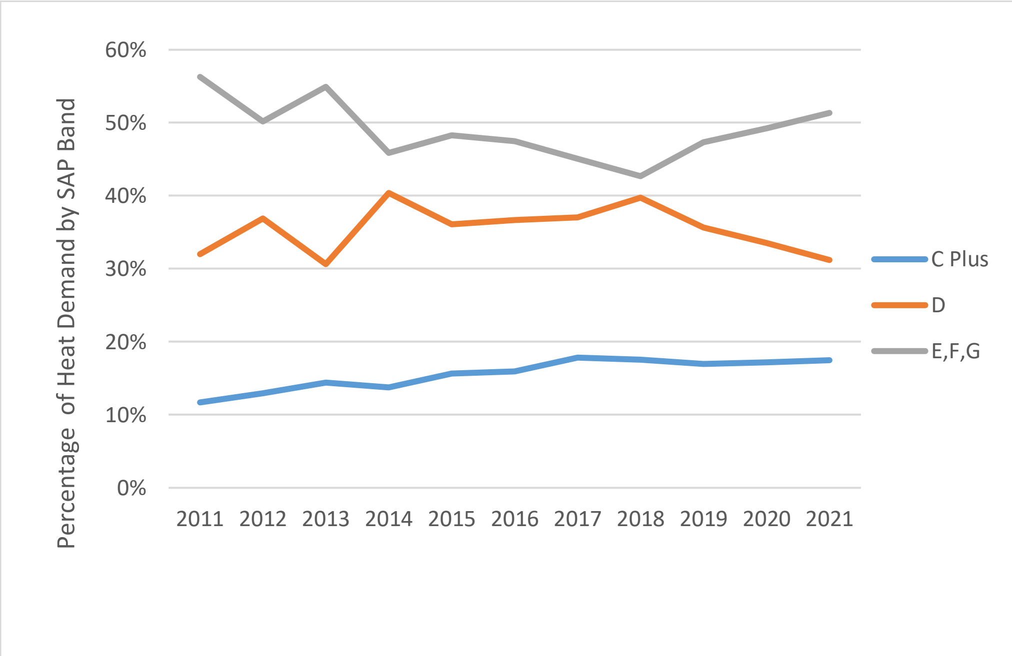


The small sample size of the SHCS, further reduced by filtering for electrically heated properties is likely responsible for the variability visible in Figure 4-4.

It is likely that in Figure 4-4 the overall trends of the graph are accurate, the percentage of properties that are classed as band C or above are increasing whilst the percentage of properties that are classed as D have fallen in recent years. The inclusion of low-carbon heating technologies will require the installation of better insulation, and it is expected that more domestic homes in Scotland will have better energy efficiency standards. However, the year-on-year change as shown in the SHCS data may not be entirely accurate due to the small sample size. The percentage of the domestic heat demand from properties in each SAP band can be viewed in

Figure 4-5.

Figure 4-5: Percentage of annual heat demand by properties in each SAP band



It is noteworthy to compare

Figure 4-4 and

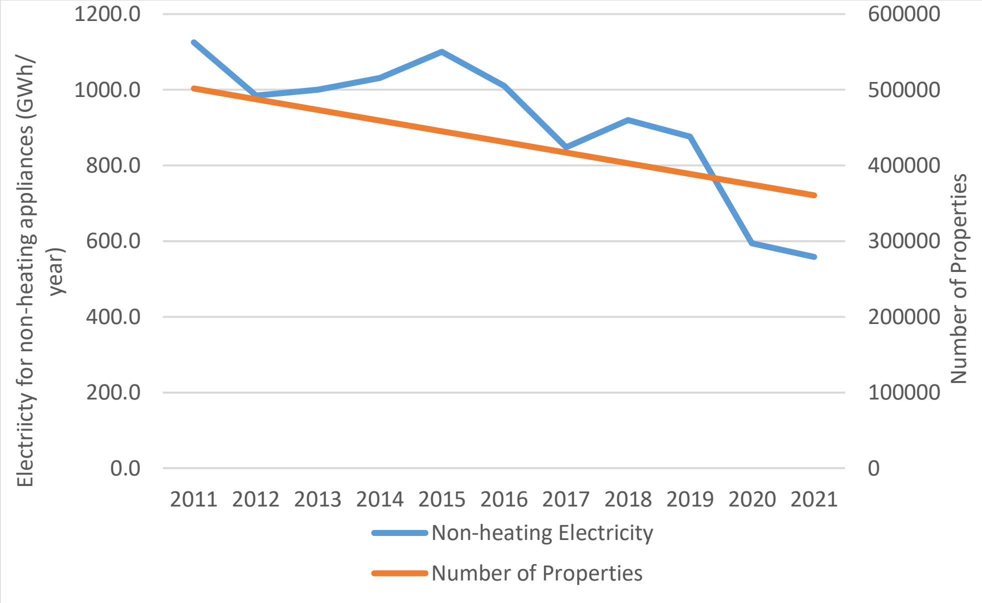
Figure 4-5. While post-2015 the proportion of properties that are classed as C Plus is only slightly less than D and E, F, G properties, the C Plus properties make up a far smaller proportion of the annual heat demand.

The non-heating electrical demand of electrically heated properties can also be calculated with the tool. This methodology is explained in detail in Appendix 2. As shown in

Figure 4-6, this demand is declining. The annual heat demand for electrically heated properties is similarly declining. Two variables contribute to this i) falling number of electrically heated properties and ii) the increased efficiency of properties. In this case, it will be due to improvements in electrical appliance efficiency, such as LED lighting. The peak visible in 2014 is due to large year-on-year variations in the data from the SHCS and may not be entirely representative. In reality, it is more likely that the non-heating electrical demand will have a similar appearance to the "total number of electrically heated properties" line in

Figure 4-6, with a slightly more negative gradient. This is as a result of the increased efficiency of household appliances.

Figure 4-6: Annual electrical demand for non-heating appliances



4.1.2 Electricity usage in electrically heated non-domestic properties

For non-domestic properties, the NDA dataset has been used as the primary source of information. The methodology used to calculate Heat Transfer Coefficients for the domestic properties has been applied to the NDA dataset to calculate heat and electrical consumption figures. The overview of the results generated for non-domestic properties in 2021 is displayed in Table 4-8.

Table 4-8: Total heat and electricity consumption for electrically heated non-domestic properties in 2021

Year		Heat Pump	Other Electric Heating	Non-Heating	Total
2021	**Electricity consumed**	256 GWh	5,174 GWh	1,658 GWh	**7,088 GWh**
	Heat generated	767 GWh	5,174 GWh	N/A	**5,941 GWh**

A far higher percentage of non-domestic properties are electrically heated compared to domestic properties, 61% and 14% respectively. There is currently no equivalent to the SHCS dataset for non-domestic properties, therefore, it was not possible to generate historical results for non-domestic properties. Table 4-9 displays the total heat demand, for 2021, from the different non-domestic property types.

Table 4-9: Total annual heat demand for non-domestic properties in 2021 by property type

2021	Heat Demand
Hotels	1,422 GWh
Offices and Workshops	1,390 GWh
Retail and Financial Services	1,106 GWh
Non-residential Institutions	780 GWh
General Assembly	382 GWh
Residential Institutions and Spaces	380 GWh
Restaurants and Cafes	289 GWh
General Industrial, Storage or Distribution	135 GWh
Other	55 GWh
Total	**5,941 GWh**

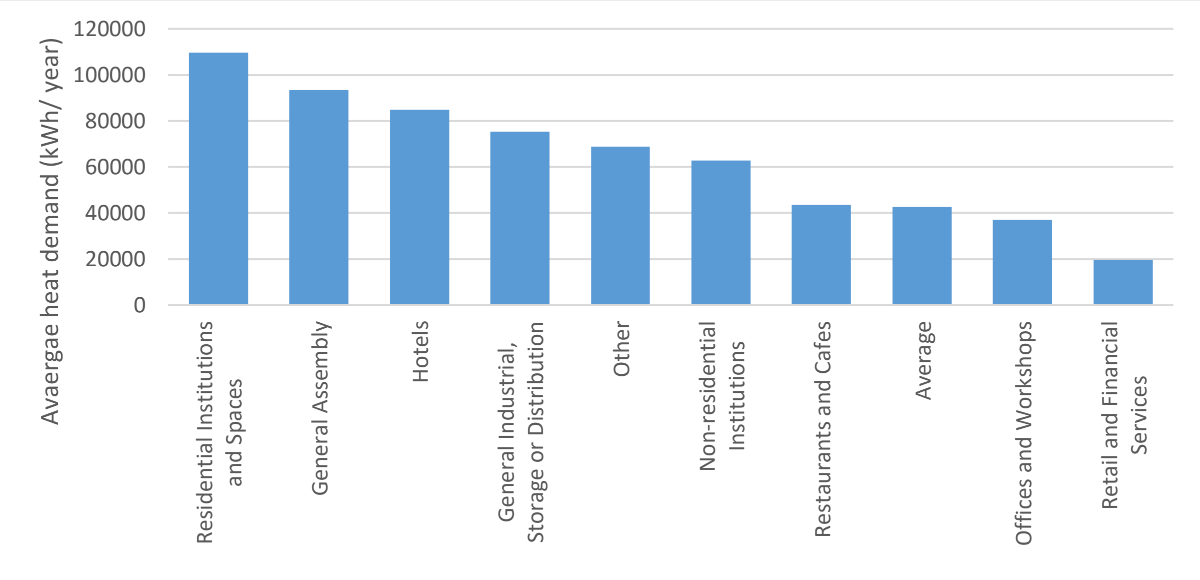
Table 4-9 highlights that three property types constitute the majority of Scotland's non-domestic heat demand: Hotels, Offices and Workshops and Retail and Financial Services. This is due to the larger quantity of these properties (see Table 4-10).

Table 4-10: Total number electrically heated non-domestic properties by type

Property Type	Count
Retail and Financial Services	55,311
Offices and Workshops	37,385
Hotels	16,746
Non-residential Institutions	12,501
Restaurants and Cafes	6,836
General Assembly	4,088
Residential Institutions and Spaces	3,461
General Industrial, Storage or Distribution	1,787
Other	799

The average heat demand for different non-domestic properties is displayed in Figure 4-7 below. The average heat demand across all non-domestic properties, generated by this model is 43000kWh/ year.

4.1.2.1 Figure 4-7: Average heat demand for different property types



Some of the less common property types, such as Residential Institutions and Spaces and General Assembly have some of the largest heat demands, shown in Figure 4-7.

The non-heating electrical demand for non-domestic properties has also been estimated. The methodology used to calculate the non-domestic non-heating electrical demand produced unrealistic numbers, this is explained in detail in Section 8.1.6. Values for the non-heating electrical demand for non-domestic buildings had to be calculated using an alternative methodology. The results for 2021 are displayed in Table 4-11: When comparing Table 4-10 and Table 4-11: , it is clear that Hotels, Offices and Workshops and Retail and Financial Services make up the largest share of the non-heating demand due to the very large quantity of these building types, not due to these categories having high average non-heating electrical demands.

Table 4-11: Non-heating demand for non-domestic properties

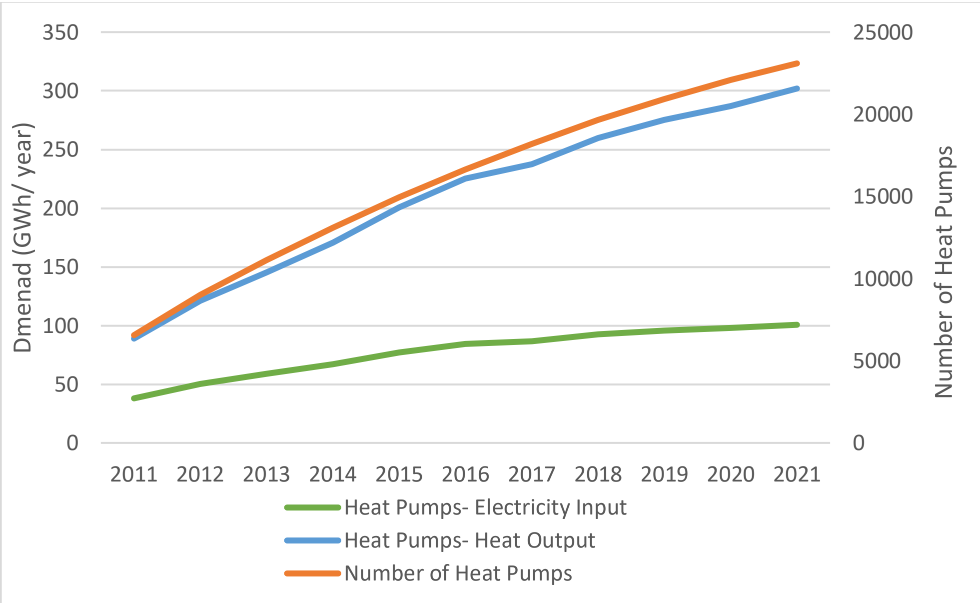
Property Type	Non-heating Electrical Demand - 2021
Non-residential Institutions	565 GWh
Retail and Financial Services	499 GWh
Hotels	236 GWh
Offices and Workshops	204 GWh
Restaurants and Cafes	88 GWh
Residential Institutions and Spaces	32 GWh
General Assembly	18 GWh
General Industrial, Storage or Distribution	8 GWh
Other	7 GWh
Total	**1,658 GWh**

4.1.3 Electricity usage by heat pumps

Whilst electrical heating from other technologies has declined in the last ten years, as discussed previously, the model indicated that the heat produced by heat pumps for domestic properties has increased significantly, from approximately 89 GWh in 2011 to 302 GWh in 2021. This is due to an increasing number of heat pumps over the last decade, making up a larger share of the primary heating technology used in electrically heated properties. This is due, in part, to the Scottish Government's support, with initiatives such as the Home Energy Scotland Loan [16] alongside other programmes such as Warmer Home Scotland scheme and the Social Housing Net Zero Heat fund [17].

As discussed in Section 3.1.2, the generalised heat pump SPF has increased from 2.28 in 2011 to 3.00 in 2021. For domestic properties in 2021, the model estimates 302 GWh of heat was generated by heat pumps, requiring approximately 101 GWh of electricity. This saves approximately 201 GWh of electricity compared to other forms of electrical heating. Similarly, the 767 GWh generated by heat pumps in non-domestic properties requires 256 GWh of electricity. This saves approximately 511 GWh of electricity per year compared to other forms of electrical heating. The historic electrical demand of heat pumps in Scotland, and their subsequent heat generation is displayed in Figure 4-8.

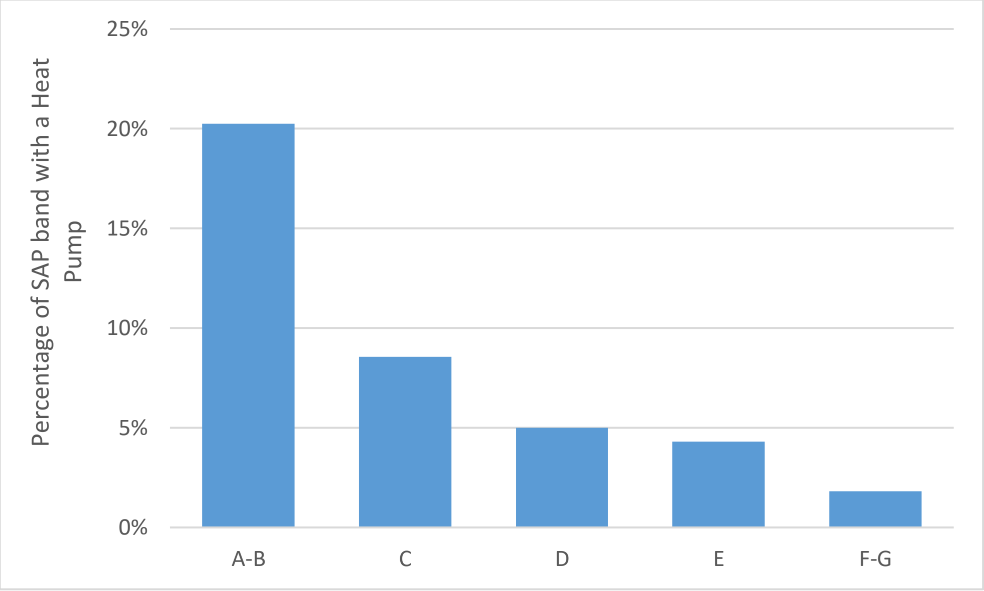
Figure 4-8 Total heat and electrical demand for heat pumps in domestic properties



According to the data from the SHCS, in 2007 1% of electrically heated domestic properties used heat pumps as their main heating technology, equating to approximately 3,500 properties. By 2019, this had risen to 8%. However, the HA database has this number at 6% for 2021. Similarly, to the overall analysis for domestic properties, SHCS was used to derive the general trend of the growth, and the final figure from HA was used. For electrically heated non-domestic properties, according to NDA, this figure is even higher, at 16%. It is clear from viewing

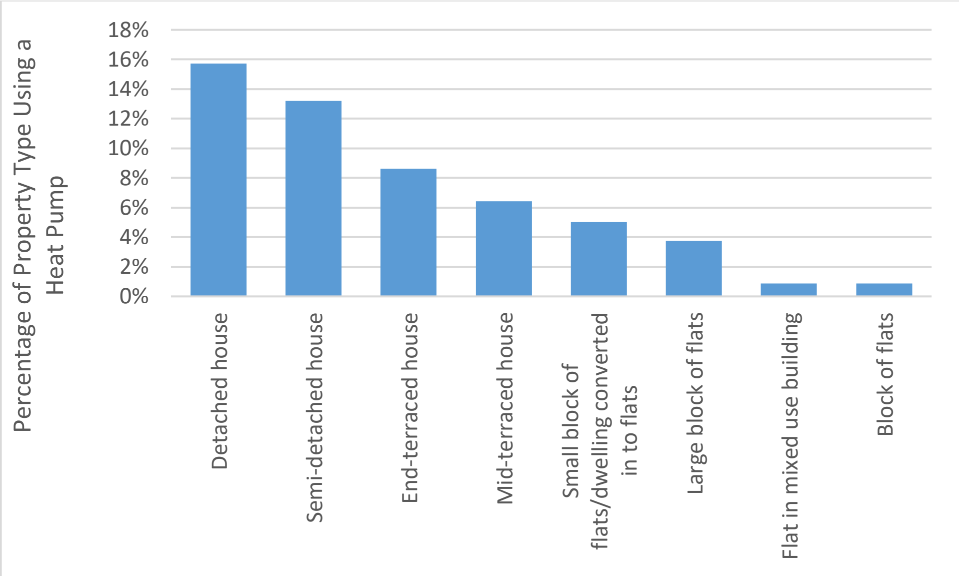
Figure 4-9, that properties with better SAP ratings are more likely to have heat pumps.

Figure 4-9: Percentage of domestic properties using a heat pump as the main heating technology, split by SAP band



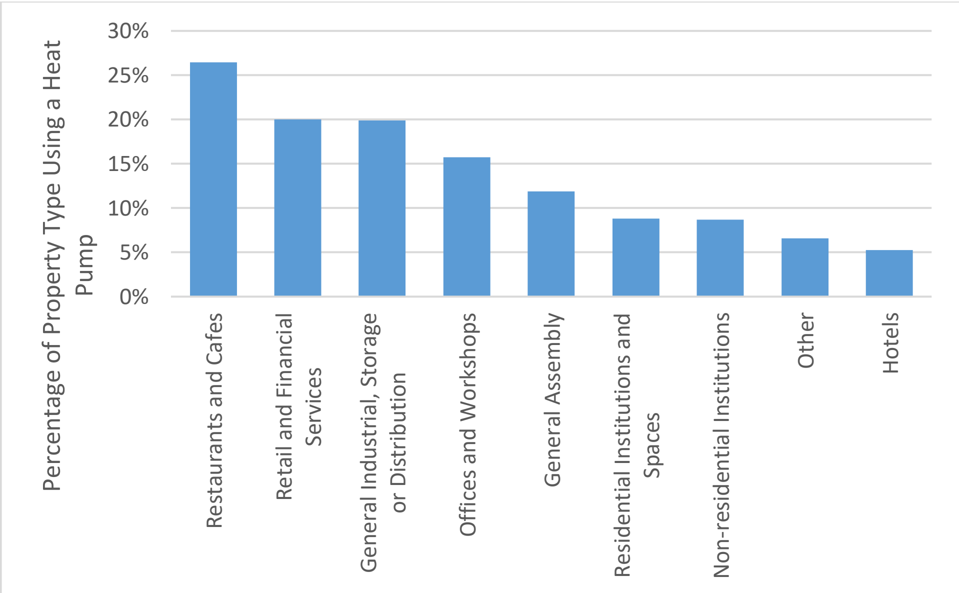
As shown in Table 4-4, semi-detached houses made up 16% of the electrical heating demand whilst properties classed as being in a block of flats made up 14%. However, the technologies used for these two property classes differs significantly, as seen in Figure 4-10, 16% of detached houses and 13% of semi- detached houses used heat pumps as their main heating technology. In comparison properties classed as a flat within a block of flats or a mixed used building, both only had heat pumps as their main technology in 1% of cases. These properties were also far more likely to be using standalone room heaters as their main heating technology compared to detached and semi-detached properties. A possible explanation for this is the availability of space in detached and semi-detached homes when compared to flats.

Figure 4-10: Percentage of each electrically heated property type using a heat pump as main heating technology



The proportion of non-domestic electrically heated buildings that utilise a heat pump also varies significantly between different building types, see Figure 4-11.

Figure 4-11: Percentage of each non-domestic property type using a heat pump as their main heating technology



4.1.4 Individual property tool

The tool developed has the capability to generate a typical heat demand for a building. Information can be entered regarding the property type, location and SAP band rating (for domestic properties) and an approximate heat demand can be generated. See Table 4-12 for an example of this for a domestic property and Table 4-13 for a non-domestic property.

Table 4-12: Approximate heat demand for a specific domestic property

Building Category	Building Type	Local Authority	SAP Band	Degree Days	Heat Transfer Coefficient (kW/K)	Heat Demand (kWh/ Year)

Domestic	Semi-detached house	Stirling	C	2,398	0.19	11,179

Table 4-13: Typical heat demand for a specific non-domestic property

Building Category	Building Type	Local Authority	Degree Days	Heat Transfer Coefficient (kW/K)	Heat Demand (kWh/ Year)
Non-domestic	Offices and Workshops	West Lothian	2,367	0.64	36,580

This tool could be used to estimate the approximate change in heating demand in specific locations and for specific property types. This would allow the impact of potential changes in the housing stock to be calculated.

4.1.5 Model results when using SHCS as source of input data

The Scottish Government requested that a version of the tool to be made available that uses data from the SHCS for the present-day inputs as well as to generate the historical figures. As a result, a second version of the excel tool was produced to include the inputs from the SHCS directly.

Data from HA has only been used to provide the Heat Transfer Coefficients tiers discussed earlier, while all the other data, present-day input and historical, comes from the SHCS. In the initial tool, data from the SHCS is used for the historical results, however this data has been scaled to fit with the HA data. In this version of the tool, this scaling has been disregarded.

Due, predominantly, to the large difference between the amount of electrically heated buildings in both data sources, the figures generated for electricity and heat consumption differ as shown in Table 4-14 and Table 4-15.

Table 4-14: Results generated using SHCS inputs- 2011

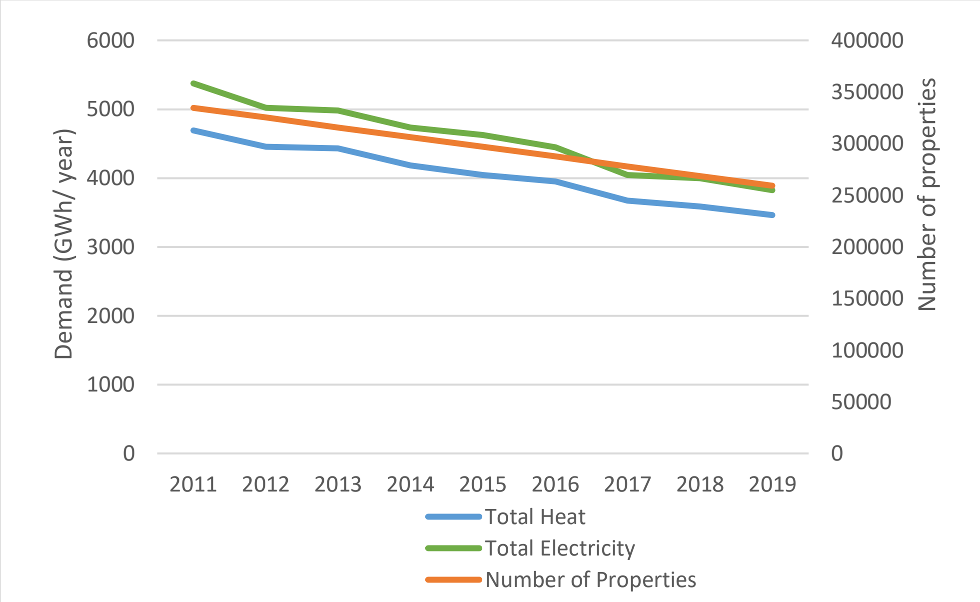
	2011 Results	
	SHCS	**HA**
Heat	4,692 GWh	6,803 GWh
Electricity	5,374 GWh	7,877 GWh

Table 4-15: Results generated using SHCS inputs- 2019

	2019 Results	
	SHCS	**HA**
Heat	3,462 GWh	4,805 GWh
Electricity	3,824 GWh	5,162 GWh

Comparing Figure 4-3 to Figure 4-12 highlights that the decline in heat and electricity for electrically heated properties is less marked when drawing on SHCS data rather than HA data. HA contains approximately 85,000 more electrically heated properties than the most recently available data from the SHCS, for 2019, which is the primary reason why the figures generated using the first tool are significantly larger.

Figure 4-12: Historical results using SHCS input data



When using the SHCS as the input data source, the results specifically regarding heat and electricity consumption for heat pumps also differ, see Table 4-16 and Table 4-17 for comparison.

Table 4-16: Heat Pump results generated using SHCS inputs- 2011

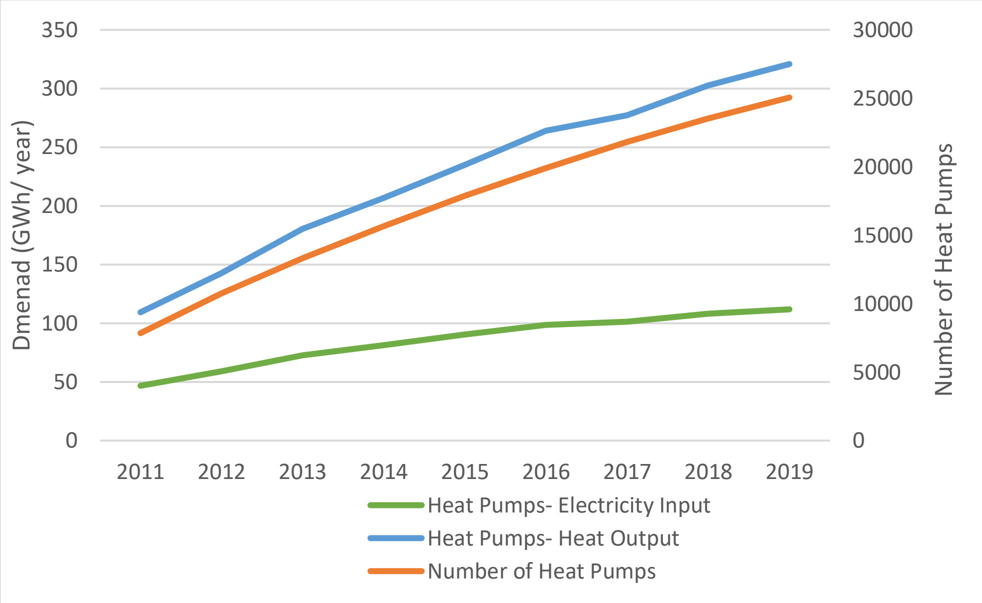
2011		
	SHCS	**HA**
Heat	110 GWh	89 GWh
Electricity	47 GWh	38 GWh

Table 4-17: Heat Pump results generated using SHCS inputs - 2019

2019		
	SHCS	**HA**
Heat	323 GWh	275 GWh
Electricity	113 GWh	96 GWh

Drawing on SHCS data results in the model generating higher heat and electrical demands than those derived using HA data as a result of the higher heat pump deployment rate in the SHCS. How the heat/ electrical demand from heat pumps changes from 2011- 2019, in this model, is visible in Figure 4-13. For the version of this tool using input data from HA, the heating technology for each property type is specified, for example, the total quantity of semi-detached properties using heat pumps is known. However, for the tool using input data from the SHCS, the number of properties using a heat pump has been provided as an overall percentage to all property types. This is unlikely to be the case in reality which will reduce the accuracy of the results presented in this version.

Figure 4-13: Historical heat pump figures using SHCS inputs



Estimates of non-heating electrical demand differ between the two approaches with values derived using the HA being greater than those derived using the SHCS (Table 4.18). This can be explained by virtue of it being proportional to the amount of electrically heated properties, which differs between the HA and SHCS data.

Table 4-18: Comparison of non-heating electrical consumption between both data sources

	SHCS	HA
2011	746 GWh	1,125 GWh
2019	572 GWh	558 GWh

4.1.6 Comparison of results

As well as comparing the result of the HA input model and the SHCS input model to each other, it is also beneficial to compare the results to published data from the Scottish Government. The Scottish Government publishes figures for all domestic and non-domestic electrical usage. However, this is not specifically related to electrically heated properties alone and encompasses properties heated by other fuels such as gas central heating. As a result, these figures will be significantly larger than the figures developed in this project. See Table 4-19 for a comparison of the results of each domestic model with the published results for total domestic electrical consumption [18]. Similarly, see Table 4-20 for a comparison of the outputs for the NDA model with published results for total non-domestic electrical consumption [18].

Table 4-19: Comparison of domestic model results with published domestic figures

2019 Results			
	SHCS	**HA**	**Published Results**
Electricity	3,824 GWh	5,162 GWh	9,625 GWh

Results

Table 4-20: Comparison of non-domestic model results with published non-domestic figures

	NDA - 2021	Published Results- 2019
Electricity	5,423 GWh	14,443 GWh

As historical results could not be generated for the NDA model, in Table 4-20, 2021 figures for the model are being compared with published figures for 2019.

Overall, there is a strong indication that the results generated for 2019 using the HA model are closer to the published results compared to using the generated results directly from the SHCS.

4.2 Low-carbon transport

4.2.1 Road transport

Following the methodology presented in Section 3.2, the road transport results for the annual mileages for the different classes of vehicles based on MOT data and Department for Transport statistics, as well as the resulting energy consumption are presented in this section.

The number of Ultra Low Emission Vehicles (ULEVs) across the different types that we analysed are presented in Table 4-21.

Table 4-21: ULEV Vehicle types and numbers for 2020

	Motorcycles	Cars	LGV	HGV	Buses and coaches
Number	162	19,918	797	9	35

Other types of vehicles such as forklifts, agricultural vehicles, diggers etc. were excluded from the assessment as they represent about 0.7% of the total number of low-carbon vehicles and no reliable usage pattern could be established for them to complete the analysis.

The average mileages for motorcycles, cars and LGVs were calculated based on MOT data (see Appendix 2 Section **Error! Reference source not found.**).

For buses and HGV, DfT statistics were used to obtain average annual mileages between 2010 and present day. The average annual mileage for 2020 is presented in Table 4-22.

Table 4-22: Average annual mileage for HGV, buses and coaches in 2020

	Motorcycles	Cars	LGV	HGV	Buses and coaches
Mileage	1,967	6,942	11,380	20,505	47,273

The energy consumption analysis results are presented in Table 4-23.

Table 4-23: Energy consumption figures for ultra-low emission road transport, Scotland, 2020

	Motorcycles	Cars	LGV	HGV	Buses

Energy consumption (Wh/mile)	19.3	257	350	2,448	2,170

An average figure was taken for electric motorcycles from a low end and high-end value for energy consumption presented in literature [19].

For cars, the energy consumption figures are based on the average of the three most established vehicles (Nissan Leaf at 260Wh/mile, Tesla Model 3 at 240Wh/mile and Renault Zoe at 270Wh/mile) [20].

In the category of LGV, the dominant vehicle is the Nissan e-NV200 Combi (350Wh/mile) representing nearly 40% of the total. Its energy consumption was used in this analysis [20].

The HGV and bus energy consumption figures (2,448Wh/mile and 2,170Wh/mile) were established through a review of the literature [21] [22].

A round trip battery efficiency of 85% was applied, and making provisions for future analysis of hydrogen vehicles, a FCEV efficiency of 64% was assumed [23] [24].

To calculate the energy consumption by plug-in hybrid vehicles, the utility factor established in Section 4.2.1 was applied to the same typical energy consumption as with battery electric vehicles, the expected annual mileage, and the number of vehicles. Applying the utility factor allows for the electrical energy consumption of the PHEVs to be isolated.

The 2020 figures for number of low-carbon ULEV vehicles and total energy consumption are presented in Table 4-24.

Table 4-24: Road transport number of vehicles and total energy consumption 2020

	Motorcycles	Cars (BEV)	Cars (PHEV)	LGV (BEV)	LGV (PHEV)	HGV	Buses
Number of vehicles	162	10,551	9,212	754	45	9	35
Total energy consumption (GWh)	0.01	22.12	5.79	3.46	0.06	0.5	4.22

The results show that cars are the most significant category of low-carbon road vehicles both in terms of number of vehicles and energy consumption. LGVs numbers show that there is some uptake in this class. There are a small number of motorcycles and as a result these comprise a negligible contribution to overall energy consumption. Buses and HGVs represent the smallest number of vehicles, however they have a comparatively high contribution to the overall energy consumption.

An analysis of hydrogen cars, LGV, HGV and buses was not carried out due to the lack of available statistics in the dataset that was used. Data on the number of hydrogen and biofuel fuelled transport in Scotland is not available to process due to the small quantities of vehicles that are currently active on the roads.

4.2.2 Rail transport

This section presents the results for the total energy consumption of the rail transport in Scotland. In the case of rail transport, very limited analysis was necessary to obtain the final energy consumption figures, as they were provided by the respective rail operators.

Network Rail provided the total energy consumption from the substations that supply traction demand. It is expected that this covers the consumption of all rail operators that use Network Rail's electrified sections in Scotland. The figures were provided for 2019 and 2020.

For Edinburgh Trams, half-hourly data series of energy consumption from the substations that exclusively supply the traction demand were provided. The data series cover 2016 to 2020.

Similarly, Glasgow Subway provided half hourly data series of energy consumption from their rolling stock. The data covers 2018 to 2020.

The total energy consumption figures for rail transport in Scotland are presented in Table 4-25.

Table 4-25: Total energy consumption of low-carbon rail transport in Scotland

	2016	2017	2018	2019	2020
Network Rail	Not available			351 GWh	279 GWh
Edinburgh Trams	4.18 GWh	5.50 GWh	5.70 GWh	5.66 GWh	4.23 GWh
Glasgow Subway	N/A	N/A	6.84 GWh	6.73 GWh	5.77 GWh

Additionally, Edinburgh Trams provided annual mileages for their rolling stock. They were used to calculate the energy consumption per mile and the results are presented in Table 4-26.

Table 4-26: Annual mileages for Edinburgh Trams

	2016	2017	2018	2019	2020
Total annual mileage	1,123,185	1,389,902	1,422,539	1,433,831	929,950
Energy consumption per mile	3.7 kWh	4.0 kWh	4.0 kWh	3.9 kWh	4.6 kWh

The results show that the rail operators using Network Rail's network are the biggest consumers of energy in the rail transport sector. They are responsible for 96.5% of the total energy consumed by the sector. This is an expected result, as the trains using this network are larger in number and travel far greater distances at greater speeds than Edinburgh Trams or Glasgow Subway.

In addition to the above, Transport for Scotland provided data on behalf of ScotRail, which is the biggest national train-operating organisation in Scotland. The data supplied provide a breakdown of the following:

- Total Net kWh of electricity consumption for all electrified rail services in each calendar year
- Total distance travelled for all rail services in miles in each calendar year
- kWh per mile indicator for each year

The results are as follows:

Table 4-27: Total electricity consumption and distance travelled for electrified rail transport which is owned by ScotRail

Financial year	Total kWh consumption	Vehicle Million Miles	kWh per miles
15/16	161,719,489	45	3.53
16/17	163,596,388	52	3.14
17/18	159,186,118	50	3.14
18/19	179,721,755	58	3.06
19/20	245,985,150	77	3.26
20/21	199,824,274	55	3.01

The data provided by ScotRail shows that annual electricity consumption on electrified rail tracks in Scotland increased substantially pre-pandemic and then gradually decreased in 2020 at the heights of the Covid-19 pandemic.

5 Key considerations for future datasets

As discussed in Sections 3.1.1 and 3.1.2, several different datasets were used to produce this model. 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 with:

- Satisfactory level of detail
- Good coverage of the domestic and non-domestic building stock in Scotland
- High confidence in the presented data

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

The two main sources of information for this study were HA and NDA. 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 can be skewed towards new builds and rental property, thereby not providing a representative picture of the domestic housing stock. 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 approximately 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.

5.1 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 EPCs suffer from significant drawbacks:

- Not all properties have an EPC. They have been required since 2008 for new buildings and any property being rented or sold. This creates a skew in the EPC data towards new buildings 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 will 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 resulting from this study. Extending the need for an EPC to an increasing number of properties would undoubtedly be beneficial for increasing the accuracy and reliability of the data, but it comes at a significant cost and would require robust justification.

However, there is some scope to improve the quality of data used to update the model created for this study, particularly for heat pump heated properties.

The Microgeneration Certification Scheme (MCS) is a quality assurance scheme for renewable energy and renewable heating installers. In all likelihood the vast majority of heat pump installations are carried out by such installers. A collaboration with the MCS on data capturing of new installations could provide reliable information on heat pump numbers that are deployed each year. The information that could be gathered would include:

- Property type
- Type of heating that the heat pump replaces
- EPC band (if available)

This would allow the Scottish Government to accurately reflect increases in heat pump numbers and decreases in other forms of heating in the appropriate property type.

5.2 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 and cooling demand.

This variability results in difficulties in assigning properties into a 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.

The small sample size and variability of stock results in average figures across building type categories that are unlikely to be accurate

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 would need to be captured. This could take the form of:

- A campaign to increase the number of EPCs
- Capturing 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
- Collaborating with Zero Waste Scotland's energy efficiency business support service to capture limited information.

5.3 Data for low-carbon transport

The data sources used to obtain information on low-carbon transport are sufficient to provide a high-level overview of total energy consumption figures. However, there are some notable gaps that will need to be addressed in the future to obtain a more detailed picture:

- Department for Transport Licensing Statistics does not provide a breakdown of "other fuels" for cars and LGV, and does not provide a breakdown between BEV, FCEV and biofuel HGV and buses. This is due to the low numbers of these vehicle / fuel types. As these become more widespread it will be important to be able to access more detailed information on the associated vehicle numbers
- To obtain more details on the energy consumption from rail transport, details on the total electricity consumption and train journeys from all rail operators in Scotland would be beneficial. Over the course of the project, Network Rail provided total electricity traction consumption over a 2-year period for Scotland as a whole; however, information on total distance travelled could only be obtained from ScotRail. Although ScotRail are the biggest train operating company in Scotland, there are other small train operating companies Capturing this information would allow the energy consumption per mile to be calculating using all of combined data from the parties involved, which will allow further comparisons with road transport.

To updating the model in future years, the Scottish Government will need to:

- Obtain the latest mileage statistics for cars, motorcycles and LGV from online sources or use the developed python script to extract and analyse the anonymised MOT data available online.

- Obtain UK government statistics for HGV and buses annually and update the model.
- Engage with Network Rail, Edinburgh Trams and Strathclyde Passenger Transport Authority to receive up-to-date data on mileages and energy consumption.

6 Findings and conclusions

This project has developed a methodology and approach for generating annual time series estimations of electricity consumption in domestic and non-domestic buildings (split between heating and non-heating purposes); heat pump electricity consumption; and low-carbon energy use in the transport sector.

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. This enabled us to estimate the total heating demand and the corresponding electricity consumption in an electrically heated building. The SHCS results were used to understand the trend in the uptake of electrically heated buildings over the years; this relationship was used to generate historical electricity consumption numbers by using the estimated results from HA at the present time as the baseline.

There was a lack of historical non-domestic data, so it was not possible to generate historical non-domestic figures. Two domestic models have been developed during this project; one uses 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. The key findings of these models are as follows:

6.1.1 HA Model - results

- Domestic heat pump heat demand increased from 94GWh in 2011 to 302GWh in 2021. The electricity consumption required to supply this heat increased from 40GWh in 2011 to 101GWh in 2021. This is due to the increased uptake of domestic heat pumps in Scotland. The electricity required to meet this increased heat demand has not risen as fast as the increased heat demand due to heat pump technology improving, resulting in increased SPFs.
- Other forms of electrical heating decreased their heat output from 7,073GWh in 2011 to 4,503GWh in 2021. This is due to an overall downward trend in the total number of electrically heated properties in Scotland, as well as the increased energy efficiency of Scottish domestic properties.
- Non-heating electrical consumption decreased from 1,126GWh in 2011 to 558GWh in 2021. This is also due to the decreasing number of electrically heated properties in Scotland and their increased efficiency,
- For domestic electrically heated properties, total heat demand decreased from 7,167GWh in 2011 to 4,805GWh in 2021 whilst electrical consumption decreased from 8,239GWh to 5,162GWh.

6.1.2 SHCS Model - results

- Domestic heat pump heat demand increased from 110GWh in 2011 to 323GWh in 2019. The electricity consumption required to supply this heat increased from 47GWh in 2011 to 113GWh in 2019.
- Other forms of electrical heating decreased their heat output from 4,581GWh in 2011 to 3,139GWh in 2019.

- Non-heating electrical consumption decreased from 746GWh in 2011 to 572GWh in 2011. This is also due to decreasing number of electrically heated properties in Scotland and their increased efficiency.
- For domestic electrically heated properties, total heat demand decreased from 4,692GWh in 2011 to 3,462GWh in 2021 whilst electrical consumption decreased from 5,374GWh to 3,824GWh.

6.1.3 NDA Model - results

As mentioned previously, it was not possible to generate historical results for non-domestic properties. The present-day (2021) results are:

- Heat pumps: demand of 767GWh of heat which requires 256GWh of electricity
- For other forms of electrical heating, the heat demand is 5,174GWh
- For non-heating purposes, the electricity demand is 1,658GWh
- Total heat demand is 5,941GWh
- Total electricity demand is 5,430GWh

6.1.4 Low-carbon transport

- Cars are the biggest road transport energy consumer – in 2020 there were around 20,000 low-carbon cars registered in Scotland with a total energy demand of 28GWh
- The number of low-carbon cars on the road increased to around 30,000 just in the first two quarters of 2021.
- Overall, low-carbon road transportation was responsible for around 36GWh of energy demand in 2020.
- Electrified rail transport is a much larger overall consumer of energy than road transport. Train operators using Network Rail railways, Edinburgh Trams and Glasgow Subway had a total demand of 289GWh in 2020, 279GWh of which came from demand on Network Rail.

6.2 Recommendations

A number of 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 Energy Saving Trust (which manages the HA and NDA dataset) to establish how frequently the datasets are updated and update the model accordingly.
- Extending the need for an improved EPC record to an increasing number of domestic and non-domestic properties in Scotland is needed. This would reduce the degree of modelled data used in HA and NDA and would undoubtedly be beneficial: it would increase the accuracy and reliability of the data and would allow the model developed to be updated. This may come at a significant cost to implement, but it is recommended that the Scottish Government explore approaches to improve the reliability of recorded EPC data.
- It is recommended that the degree days and heat loss coefficient tiers are reviewed every five years, as it is highly unlikely that changes in building stock will change the assumptions by a significant margin over a shorter term.

- The usage of heat pumps is set to become more common and as this happens the efficiency of heat pumps will increase. We recommend that the Scottish Government liaises with the two major network operators in Scotland (Scottish Power Energy Networks and Scottish & Southern Electricity Networks) which are likely to be well placed to provide information on the number of heat pumps connected to the network. In addition, it may be worth exploring with the Microgeneration Certification Scheme (MCS) whether it is able to provide reliable and updated data on heat pump installation numbers and efficiencies.
- 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 Energy Saving Trust (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 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 in 2019 and does not show the historical trends in electricity consumption in electrically heated properties. Data was acquired from the SHCS to show historical trends into the percentage of electrically heated property that has varied with time. This was then used to estimate historical figures for electricity consumption for heating purposes. 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.

National Energy Efficiency Data (NEED) framework is a dataset provided by BEIS, which was used to understand and estimate electricity consumption for non-heating purposes in electrically heated buildings.

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 Table 8-1 and

Table 8-2 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, it's location and its main heating technology can be entered. The domestic input page also contains information about a property's SAP band rating.

Table 8-1: Example of domestic input page for A-B SAP Band domestic properties in Aberdeen City and the number of different electric heating technologies installed at each property

A-B SAP Band Only	Boiler	Communal	Heat pump	No heating or hot water system	Other	Room heaters	Storage heaters	Total
Aberdeen City								
Block of flats	14	58	13		1	13	82	**181**
Detached house	2		10				1	**13**
End-terraced house	4				1		2	**7**
Flat in mixed use building	16	18		3	43	7	17	**104**
Large block of flats	41	385	62				439	**927**
Mid-terraced house	3				1	1		**5**
Semi-detached house		32	1				17	**50**
Small block of flats/dwelling converted into flats	12		2		1		6	**21**

The dataset provided below contains the input table data for non-domestic properties in the Local Authority area of Aberdeen City for all non-domestic properties.

Table 8-2: Example of non-domestic input page for the total number of electrically heated technologies installed in non-domestic buildings in LA area of Aberdeen City

	Air heater	Boiler	Heat pump	Other	Room heater	Total
Aberdeen City						
General Assembly	22	19	26		50	**117**
General Industrial, Storage or Distribution	1	6	24	1	44	**76**
Hotels		29	39		248	**316**
Non-residential Institutions	21	70	41	1	225	**358**
Offices and Workshops	51	139	460	3	710	**1,363**
Other		19	6		64	**89**
Residential Institutions and Spaces		37	16		74	**127**
Restaurants and Cafes	1	14	141		130	**286**
Retail and Financial Services	31	118	601	1	1086	**1,837**

8.1.2 Degree days

A key component of this methodology is the utilisation of degree days. Degree days are a measure of how many days, and by how much, 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. This temperature is chosen as the "base temperature" for European Degree Days as the generalised desired room temperature is 19°C. It is assumed that the average internal heat gain, from equipment and people, is 3.5°C. This is a generalised base temperature for all buildings, desired internal temperatures and internal heat gains vary for different building types.

Ricardo 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 8-3 for a list of each Weather Station chosen as representative of each Local Authority. Where there is no weather station located in the Local Authority, assumptions were made to select the best one for the analysis.

Table 8-3: Weather stations chosen for each Local Authority

Local Authority	Weather Station (WS) 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 31600, Edinburgh Airport, Edinburgh	There is no available WS in Falkirk. Data from these two WS has been averaged together.
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.
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.

8.1.3 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 Heat Loss Coefficients have been calculated using the estimated heat consumption which is calculated using the SAP methodology. It is important to note that this model is generating the Heat Loss Coefficient based off this input data and as a result, may not be entirely precise, but is likely the optimum situation viable with the data provided. HA does not contain information on tenement properties. Due to their typical features, high ceilings and large windows, they often have quite poor heat efficiency. In future iterations of HA, it may be worthwhile to collect information specifically on tenements to understand their heat demand. Rental properties, properties in urban areas and new-builds are more likely to have had an EPC issued recently, therefore these property types are overrepresented in the EPC database. HA and NDA model the characteristics of properties that do not have information available, the release notes for both datasets discusses the skew of the EPC database and describes how the Energy Saving Trust has attempted to counter it during the modelling process.

The tiered 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. For some property types, the Heat Transfer Coefficient of Band A-B/ C was higher than the Heat Transfer Coefficient for Band D, E, and F-G. 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 becomes available, the tier system may be viable in a future iteration of the tool. See Table 8-4 and

Table 8-5 for the Heat Transfer Coefficients for domestic and non-domestic properties.

Table 8-4: Domestic Heat Transfer Coefficients

Heat Transfer Coefficients (W/m²K)	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 into flats	1.44	1.93	2.84	3.98	4.61

Table 8-5: Non-domestic Heat transfer Coefficients

Property Type	Heat Transfer Coefficient (W/m^{2}k)
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

8.1.4 Heat demand calculations

Using the Heat Transfer Coefficients, the Degree Days for each Local Authority and average floor areas for each property type, a characteristic annual heat demand for each property can be calculated. The input pages in the ‘SG Electrical Heating – Excel Tool’ will allow the Scottish Government to specify the quantity of each property used. When converting this heat demand into the electrical demand used to produce it, the following assumptions have been made:

- Electrical heaters are 100% efficient, the majority of losses in electrical appliances are heat
- The generalised heat pump SPF will vary from 2.28-3, as discussed in Section 3.1.2

Heat pumps operate by extracting heat from either the ground or the air, they can therefore have an output of heat energy that is greater than the input of electrical energy.

8.1.5 Historical calculations

Data was provided to us by the 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 electrically heated
- For each electrically heated building type- percentage in each SAP band
- Percentage of electrically heated properties using each heating technology

Regression analysis was carried out for each variable in the datasets received from the SHCS. Likely due to the small sample size of the survey, most of the data had low correlation coefficients (R^2) coefficients, with weak correlations. Two variables had R^2 coefficients greater than 75%. One was the percentage of electrically heated properties that have heat pumps, this has risen consistently over the years. The other is the total number of electrically heated properties, this has decreased consistently over the last ten years. Regression coefficients for these two variables were generated and used to calculate values for each year

Due to the small sample size of the SHCS survey, this data would produce some anomalous results as seen in Table 8-6. It is highly unlikely that the percentage of electrically heated properties with heat pumps was 4% in 2013, 3% in 2014 and 7% in 2015. It is more likely it was a small year-on-year increase. The more valuable data to be obtained from the SHCS is the overall trend, instead of specific figures for specific years.

Table 8-6 also contains the historical percentage of electrically heated properties with heat pumps, but using regression coefficients instead of the raw data. HA states that for 2021, 6.17% of domestic properties, that are electrically heated, are using heat pumps. If the regression coefficient is carried on for 2021, the most recent SHCS data is for 2019, then this would be 11.07%, as seen in Table 8-6. Due to the significantly larger size of the HA dataset relative to the SHCS sample size, it likely that HA is more accurate.

This regression coefficient was then applied to the HA 2021 value and then taken backwards to calculate historical results based on the relative year-on-year changes in the SHCS data, not the absolute change. This same process was carried out for the total number of electrically heated properties. The relative change is used as the absolute numbers in the SHCS and HA are different. There is a large discrepancy between the total number of electrically heated properties in the 2021 HA data and the most recent (2019) SHCS data. Using solely SHCS for historical data and HA for present day data would result in a very large and unrealistic "jump" between the historical data and the present-day results. Therefore, for the first model discussed in the report, the relative change in the number of electrically heated properties in the SHCS is applied to the present-day number of electrically heated properties in Home Analytics. A second model has been produced where the number of electrically heated properties is not scaled up to the number in Home Analytics.

Table 8-6: Regression analysis of SHCS data to identify trends in the uptake of electrically heated properties fitted with heat pumps. Note the HA numbers were used directly for 2021 and the average was taken between 2019 and 2021 to generate 2020 numbers as this was unavailable in the dataset for SHCS

Percentage of Electrically Heated Properties with Heat Pumps			
Year	**SHCS Data**	**Regression Analysis**	**Adjusted to HA Baseline**

2010	2%	1.47%	0.82%
2011	3%	2.35%	1.31%
2012	2%	3.22%	1.79%
2013	4%	4.09%	2.28%
2014	3%	4.96%	2.77%
2015	7%	5.84%	3.25%
2016	7%	6.71%	3.74%
2017	9%	7.58%	4.22%
2018	9%	8.45%	4.71%
2019	8%	9.33%	5.20%
2020		10.20%	5.68%
2021		11.07%	6.17%

Another step in the process of calculating historical figures involved approximating the categories in HA with the categories in SHCS. This is regarding SAP band as well as property type. Table 8-7 and **Error! Reference source not found.** below show how the categories have been approximated together, this is indicated by the colour coding. This specific example involves converting the number of each property type in each SAP band into the categories used in the SHCS.

Table 8-7: Property type categories and SAP Band split in HA Data

HA – Number of EH Properties	A-B	C	D	E	F-G
Block of flats	3,163	20,163	24,791	13,405	6,815
Detached house	2,526	5,422	11,295	10,369	13,143
End-terraced house	568	2,564	8,035	6,642	4,759
Flat in mixed use building	3,434	13,210	12,325	7,756	5,082
Large block of flats	7,939	26,784	15,755	6,130	2,802
Mid-terraced house	673	4,488	12,542	9,506	5,595

Semi-detached house	1,459	6,097	15,878	12,080	8,657
Small block of flats/dwelling converted in to flats	1,671	11,267	17,985	10,977	6,929

Table 8-8: Property type categories and SAP Band split in SHCS format

Number of Properties from HA in SHCS Categories	C Plus	D	E, F, G
Detached	7,948	11,295	23,512
Semi-detached	10,688	23,913	32,138
Terraced	5,161	12,542	15,101
Tenement	29,582	30,310	30,744
Other flats	58,049	40,546	29,152
Detached	7,948	11,295	23,512
Semi-detached	10,688	23,913	32,138
Terraced	5,161	12,542	15,101

This process is used for converting the total number of properties, in HA categories, to the total number in SHCS categories, as seen above. This same process is also required for converting the total heat demand for each property type and SAP band in the HA format to the SHCS format. The SHCS also provided historical data on how many electrically heated properties there are in Scotland, grouped by property type, see

Table 8-9.

Table 8-9: Number of electrically heated properties, by property type in Scotland

Electrically Heated Properties by Property Type						
Year	**Detached**	**Semi-Detached**	**Terraced**	**Tenement**	**Other flat**	**Total**
2010	30,407	49,803	70,184	113,672	65,973	**33,0039**
2011	35,336	42,994	60,084	131,209	61,902	**33,1525**

2012	40,169	33,260	63,411	137,892	59,337	**33,4069**
2013	35,298	52,214	52,061	116,132	56,530	**31,2234**
2014	38,390	43,281	63,638	101,429	67,852	**31,4590**
2015	38,552	39,814	48,760	108,127	56,823	**29,2075**
2016	42,970	40,770	35,622	92,116	58,228	**26,9706**
2017	34,052	39,477	60,236	107,740	54,123	**29,5628**
2018	33,286	45,634	37,396	81,006	50,405	**24,7728**
2019	36,187	31,020	43,959	110,642	52,711	**274,519**

Another dataset obtained from the SHCS was the historical breakdown of what percentage of each electrically heated property type is in each SAP band. This data was provided on a yearly basis from 2011- 2019. An example of this data, for 2013, is provided below, see Table 8-10.

Table 8-10: Historical SAP band/ property type data which shows the percentage of properties by each SAP band over Scotland in 2013.

2013	C Plus	D	E, F, G
Detached	5%	28%	67%
Semi-detached	10%	35%	56%
Terraced	4%	49%	48%
Tenement	43%	29%	29%
Other flats	54%	25%	20%
Total	28%	32%	39%

Multiplying the total number of each electrically heated property type, in 2013, from Table 8-9, with the percentage of each property type in each SAP band, from Table 8-10 allows the total number of each property type in each SAP band for a specific year, see Table 8-11.

Table 8-11: Historical number of properties in each SAP band/ property type category which shows the number of properties for each property type across each SAP band in Scotland in 2013

2013	C Plus	D	E, F, G

Detached	1,785	9,994	23,915
Semi-detached	5,280	18,480	29,568
Terraced	2,106	25,796	25,269
Tenement	50,497	34,056	34,056
Other flats	30,868	14,291	11,433

The total heat demand for a yearly basis, shown in Table 8-12 was then calculated, as seen in Equation 1.

$$\text{Equation 1: } H\ (C/DH/\ 2013) = \frac{N\ (C/DH/2013)}{N\ (C/DH/2021)} \times Heat\ (C/DH/\ 2021)$$

H= heat, N= number of properties, (C/ DH/ 2013) refers to Band C+ detached houses in 2013, (C/ DH/ 2021) refers to the 2021 data for Band C+ detached houses, from HA.

Table 8-12: Total heat demand for each sub-category in 2013

2013	**C Plus**	**D**	**E, F, G**
Detached	23.5 GWh	197.2 GWh	636.2 GWh
Semi-detached	50.4 GWh	271.3 GWh	605.7 GWh
Terraced	18.9 GWh	355.1 GWh	472.6 GWh
Tenement	330.2 GWh	399.1 GWh	572.4 GWh
Other flats	220.3 GWh	128.0 GWh	125.0 GWh

This heat demand figure is then converted to an equivalent electrical demand. The assumptions discussed in Section 8.1.4 regarding electric heater efficiency and heat pump SPF are utilised. Unfortunately, the SHCS could only provide the percentage of all electrically heated properties that use heat pumps. The sample size of the survey, when specifying for heat pump usage by SAP band/ property type, is too small for the data to be valid. Therefore, the historical percentage of properties using a heat pump as their main heating technology has been applied equally across all building types. The calculation for total electricity demand is shown in Equation 2.

$$\textit{Equation 2: } E = H * (1 - HP) + HP * \left(\frac{H}{SPF}\right)$$

E= Electrical demand (W), H=Heat demand (W), HP= Percentage of properties using a heat pump as their main technology, SPF= Seasonal Performance Coefficient

8.1.6 Non-heating electrical demand

This project also involved calculating the non-heating electrical demand of electrically heated properties. There is no data available that provides this information specifically for Scotland. The National Energy Efficiency Data-Framework, published by the Department of Business, Energy and Industrial Strategy, provides average electrical demand figures, on a yearly basis, for different property types, for all fuel types. This average electrical demand will be inflated by the large electric consumption of electrically heated buildings. In order to calculate the non-heating electrical demand in electrically heated properties, the impact of electrically heated properties needs to be removed from this average. The NEED-UK framework provide historical average electrical demands for different property types. The data from SHCS provides historical figures for what proportion of each property type is electrically heated. This allows the possibility of generating non-heating electrical demand figures for previous years.

This is calculated using Equation 3

$$\textit{Equation 3: } E2 = E1 - (P * E_H)$$

E2= Adjusted average electrical demand, E1= Average electrical demand, P= percentage of property type that is electrically heated and EH= Electricity required for the average heat demand of this property type

This adjusted average electrical demand for each property type was then multiplied by the number of properties in each category. Data from HA was used for the 2021 figure and data from the SHCS for any years prior.

This process worked effectively when calculating the electrical demand for domestic properties, with realistic numbers calculated, see Table 8-13. The property categories in **Error! Reference source not found.** are the categories used for the NEED-UK framework. Each of these values was assigned to one of the property categories used in the SHCS or HA.

Table 8-13: Average non-heating electrical demand for different property types

Property Type	Non-Heating Electricity (kWh/ Year)
Detached	3,150
Semi-Detached	2,180
End Terraced	1,902
Mid Terraced	1,801
Converted flat	1,056
Purpose built flat	1,014

The most recently available "Typical Domestic Consumption Values" (TDCV) published by Ofgem in 2020 have "typical" electricity usages as 1800kWh per year for low use households, 2900 kWh for medium use households and 4300kWh for high use households. These results will be the average for properties across all heating fuels, therefore it is to be expected that they are slightly higher than the non-heating electricity usage for electrically heated properties.

However, when this same process was applied to non-domestic properties, the numbers generated were not realistic. For some of the non-domestic building types, a large percentage of this property type was electrically heated, up to 75% for "Retail and Financial Services". When using these larger values for "P" in Equation 3, the average non-heating figure for some building types was a negative number. This is not possible so this analysis has not been included in the tool. This is once again, likely due to the small sample of measured data that NDA is based on. Another potential reason could be due to the larger variation in the size of properties that fall into a single non-domestic property category. The solution decided upon was to use the median electrical demand provided by the ND-NEED UK framework. Each of the ND-NEED UK categories was matched to one of the property categories in NDA. This median electrical demand is then multiplied by the number of properties in each property category in NDA to obtain a total non-heating electricity consumption figure, seen in Table 4-8.

8.1.7 Low-carbon transport

The average mileages for motorcycles, cars and vans were obtained using MOT data. The analysis was carried out twice:

- Between 2020 and 2019 to obtain the latest figures.
- Between 2019 and 2018 to obtain pre-pandemic figures that were used as historic data for the past 10 years. This was deemed appropriate as research showed no significant variations in mileages year on year before the pandemic.

Figure 8-1 and **Error! Reference source not found.** present the results.

Figure 8-1 Mean and median annual mileage split by vehicle class between 2019 – 2020 (based on MOT data)

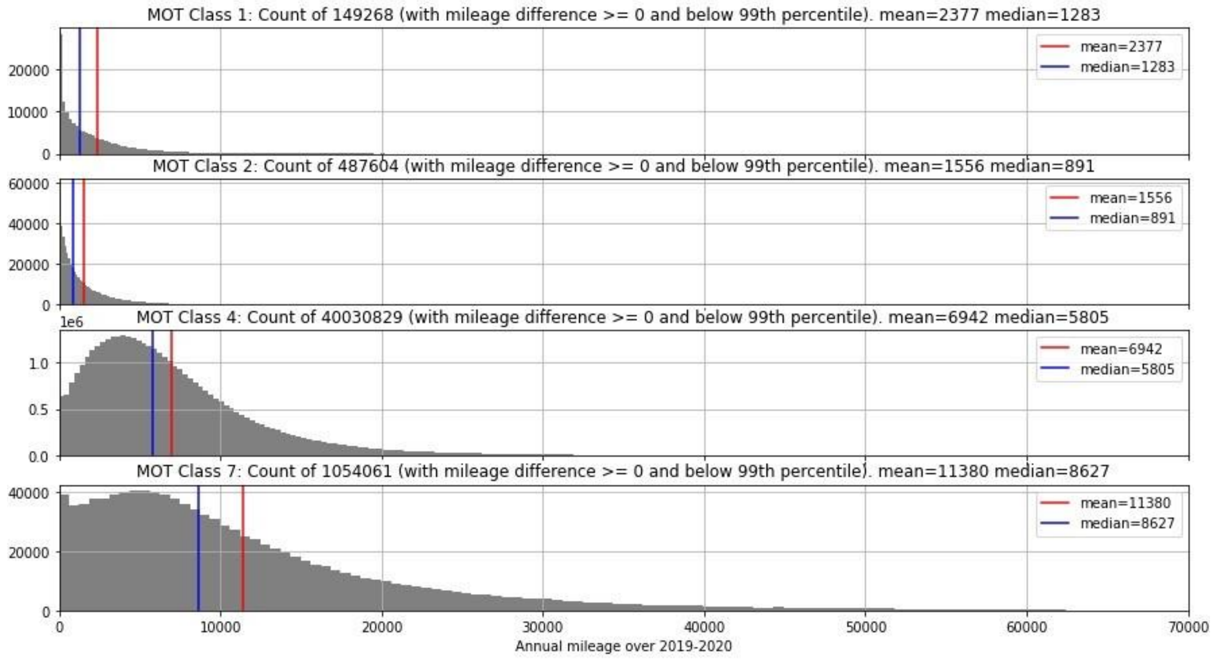
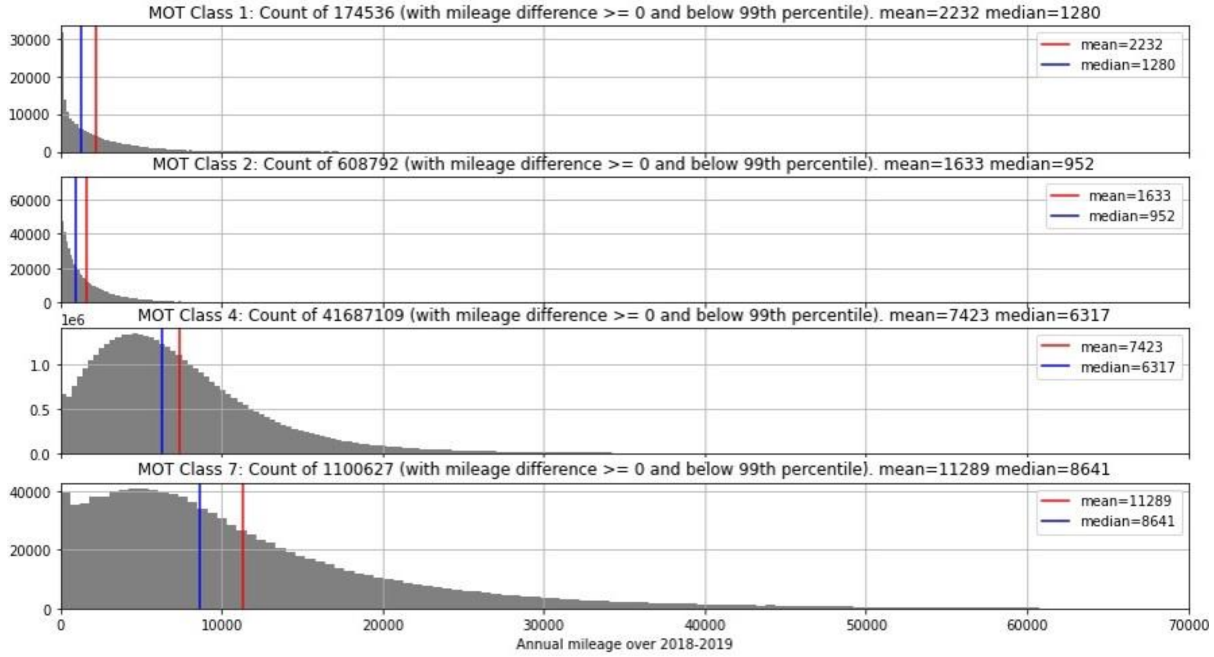


Figure 8-2 Mean and median annual mileage split by vehicle class between 2018 – 2019 (based on MOT data)



There is no considerable year on year difference between motorcycles and LGVs, however, there is a notable drop in the average mileage of cars during the pandemic.

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