Department of Mechanical and Aerospace Engineering

Study of the Impact and Mitigation Measures Associated with Widespread Electric Vehicle use in an Urban Electricity Network

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Abstract

Electric vehicles are considered to be solution to improving urban air quality, help reduce reliance on fossil fuels and reduce greenhouse gas emissions. As a result, the use of electric vehicles is increasing and is encouraged by many urban authorities.

This project assesses the possible impact that widespread electric vehicle (EV) use could have on an urban electricity network and also investigates possible mitigation measures in order to minimise the identified impacts.

The project used the city of Glasgow as the case study for the investigation. An Excel based demand profile generator tool was utilised for this investigation in order to determine substation peak electrical power demand and weekly consumption for Glasgow substations loads, with and without widespread EV reliance on the substation for charging. From this initial study it is clear that widespread electrical vehicle use significantly increases substation peak power demand and energy consumption.

The same tool was then utilised to investigate possible mitigation measures to minimise the impact of EV us on the peak power and energy demand. The tool was used to undertake a series of sensitivity studies of the various changeable settings in the tool and then determine from this the optimum settings that provide the best mitigation. These settings were carried over to a final mitigation strategy which was then applied to a representative model of a substation to determine the benefit of the mitigation measures. The mitigation measures were also evaluated for feasibility of real world implementation.

Mitigation strategies reduced the substation peak power demand by 24% and reduced the energy consumption by 42% in comparison with a base case scenario with no mitigation measures.

Acknowledgements

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Abbreviations

CHP	Combined Heat and Power
DPG	Demand Profile Generator
EHP	Electric Heat Pump
EV	Electric Vehicle
FES	Future Energy Scenarios
GCC	Glasgow City Council
GHG	Green House Gases
GSHP	Ground Source Heat Pump
LV	Low Voltage
PV	Photovoltaic
UK	United Kingdom
WNA	World Nuclear Association
WSHP	Water Source Heat Pump

1 Introduction

1.1 Project Background

Transportation accounts for a large portion of the energy used. According to Mackay (2009) approximately a third of average individual energy consumption is due to transportation, 57% of which is for personal vehicles. However, it is widely accepted that the use of conventional vehicles is a source of Greenhouse Gas (GHG) emissions that contribute to global warming concerns and significantly reduce the air quality in urban environments. As a result, authorities are under pressure to promote cleaner air quality in town and cities, and one obvious target is vehicle use.

In terms of urban transport there are two methods to reduce GHG emissions. Firstly, reduce the amount of vehicles used by encouraging use of other methods of transportation such as walking, bicycles and/or public transportation. Secondly, is to change over from conventional internal combustion engine powered vehicles and phase in Electric Vehicles (EV).

However, EVs are reliant on the electricity network for charging. At present, the impact on the grid is negligible as the relative number of EVs being used today is low. Needless to say, if the number of EV is to significantly increase, this is likely pose significant strains on the grid if no changes to infrastructure are made. Impacts on the electricity network include increasing the peak electricity demand which may exceed equipment loading limits therefore requiring network reinforcement.

The purpose of this project is to study the impacts associated with widespread EV use on an urban electricity network and also, using a dedicated profile generating tool, to investigate possible mitigation measures that can be feasibly implemented in order to minimise this impact.

1.2 Project Aim and Objectives

The primary aim of this project is to determine the mitigation measures in order to minimise the peak power flows and energy demand in a low voltage urban electricity network and hence reduce the need for network reinforcement.

In order to fulfil the project aims, the project has the following objectives:

1. Estimate a level of widespread EV use;
2. Assess the power and energy demand of an urban network prior to the introduction of widespread EV;
3. Determine the impact of widespread EV use on the urban electrify network;
4. Analyse potential strategies to mitigate the impact of EV on an urban LV network and assess improvements – use Glasgow as a case study;
5. Assess feasibility of the mitigation strategies.

1.3 Project Method Overview

This project uses Glasgow City as a case study for investigating the impacts and mitigation measures associated with widespread EV use in an urban environment. The city of Glasgow has been chosen because it is a good example of a medium sized city and an urban setting. It is one of the UK's major cities and has large number of motorists who commute in and out of the city on a daily bases from a large commuting radius. The city also has a mixture of new and old architecture, electrical and transport infrastructure. Also, this project utilises a profile generation tool developed by Strathclyde University for Scottish Power and incorporates data associated with the Glasgow City urban electricity network.

A good reason to choose a Scottish city for the study is that the Scottish Government (Transport Scotland, 2013) also has the key commitment to eliminate vehicle emissions in town and cities by 2050 as part of their climate change and energy ambitions.

There are a number of key steps in the methodology needed in order to achieve the project aim and objectives. This section of the report provides an outline of the project methodology followed.

The first part of the project is to undertake a detailed literature review to develop a thorough understanding of EV use and the necessary charging infrastructure in order to support widespread EV use. A key stage here is to use the information gathered in order to estimate future EV use (*Objective 1*). The literature review also serves to research plans for infrastructure change in Glasgow and the rest of Scotland. It also allows an understand EV charging mitigation plans in other major cities.

Following the literature review, the project utilised the City Substation Electrical Demand Profile Generator (DPG) profile generation tool (more information of the tool is provided in section 3.1). The tool allows analysis of Glasgow city substation loads from an inventory of connected building types. The tool will be used to assess network impact of increased EV use prior to implementation of mitigation measures. This will be done by comparing the grid load with and without EV demand for charging (Objective 2 and 3 respectively).

Using the DPG tool and incorporating the increased load due to the increased EV charging, an investigation will also be carried out to determine possible mitigation measures (Objective 4). The best performing mitigation strategy will be chosen based on minimizing the substation peak power demand and weekly energy demand, but also the feasibility regarding real world implementation (Objective 5). Following the mitigation investigation, the impact on the electricity network will be determined following the application of the mitigation strategy.

1.4 Project Scope, Omissions and Assumptions

The project's focus is on assessing impacts of widespread EV use on an urban electricity network and to determine mitigation strategies in order to minimise the impact on substation peak power demand and weekly energy consumption. The following is a summary of the recognised scope of the project:

Electrical Power Assessment: The project only assesses electrical power consumption and does not take into consideration other forms of energy consumption such as gas for heating.

Plug in Electric Vehicles: There are a number of EV variants available on the market. This project only considers using purely plug in Electric Vehicles which are fully reliant on charging points for battery charging. The project does not consider any other form of EVs such as Hybrid Vehicles.

Glasgow Case Study and DPG Tool: The project uses the substation network in the city of Glasgow as a case study of a typical urban LV electricity network. And the DPG holds Glasgow substation data and will be used as the tool for this investigation. Any conclusions made are based on the Glasgow data available from the tool.

Winter Season: All investigations will be modelled over for winter season as it is assumed that power demand is generally greater during the winter than any other season because of the increased heating demand.

EV Estimations: Estimations of future EV use are based on present day private vehicle habits and does not take into account any change in changes in the driving habits due to increased use of other forms of transportation such as walking, cycling or public transportation.

Electrification of Transport: The project investigation only considers the electrification of private vehicles and does not consider the electrification of other road users such as haulage and public transport.

2 Literature Review

In order to get a thorough understanding of the impact on urban electricity grid following widespread adoption of EVs, a literature review was carried out to assess existing studies of present day and widespread adoptions of EV use in Glasgow and Scotland. This will include a review of EV technology in order to determine EV energy usage based existing motorists commuting habits. The review also assesses Scottish Government and Glasgow City Council (GCC) forecasting and infrastructure planning in order to allow for increased EV use in the city.

The literature review will assess existing studies the evaluate impacts associated with widespread EV use. An assessment will also be made of EV infrastructure requirements, and how it utilizes the urban electricity network for electrical power supply, including power rates for charging and charging modes, especially those planned for Glasgow. The review also considers existing studies that have evaluated mitigation measures to minimise the impact of widespread EV use on the electricity grid.

2.1 Widespread EV Use Forecast

The Scottish government is committed to making urban environments, such as towns and cities, free from harmful emissions of conventional diesel or petrol fuelled vehicles. The principle motives behind this aim are to significantly improve the air quality, noise levels and public health within urban environments. The commitment of improving urban air quality is set by the Scottish government objective to be free of all emissions in urban areas by 2050 (Transport Scotland, 2013). Glasgow City Council (GCC) supports this policy and reverberates the ambition by encouraging motorists to convert from conventional vehicles to EVs (Glasgow City Council, 2016). In order to help insensitive drivers to convert, charging bays have been installed throughout the city to allow drivers to top up whilst they are in the city.

Glasgow and the whole of the UK have a long way to go regarding the phasing in of EV use. According to the Department for Transport (2016) the UK has approximately 38 million registered vehicles on British roads, 31 million of which are classed as cars. According to the RAC Foundation, as of early 2016 there are only approximately 58,000 EVs registered. Although, it should be noted that this is approximately 10,000 EVs more than the final quarter of 2015, showing a significant increase in EV sales.

To sum up, EV’s count for only 0.15% of vehicles registered and used in the UK today. Clearly, widespread adoption of EV use will significantly increase EV numbers and hence charging demands from the electricity grid and strategies will need to be in place in order for the electricity networks to deal with widespread EV use. Although vehicle use in Glasgow is only a small portion of the UK, it still gives a sense of the expansion of EV use yet to come.

2.1.1 Conventional Vehicle Use in the City of Glasgow

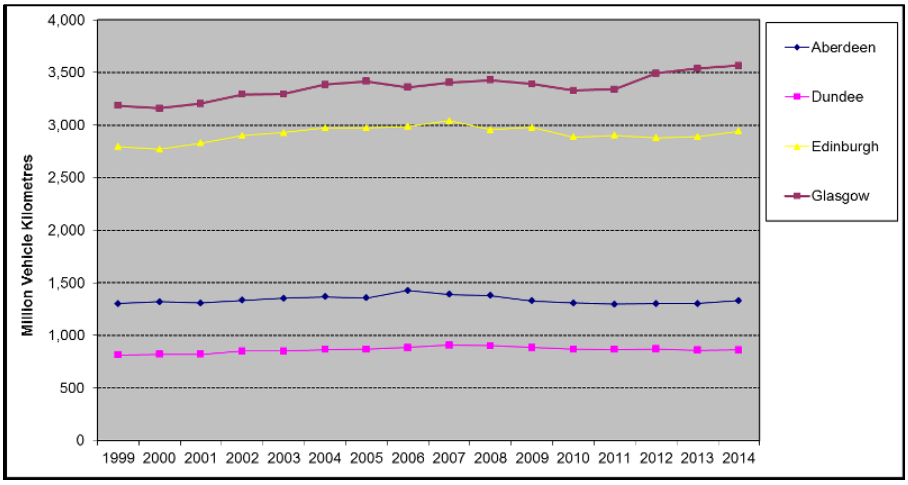

Figure 1 Traffic on all roads in Scotland’s four largest cities 1999-2014 (Understanding Glasgow, 2016)

Figure 1 above shows that in 2014, according to Scottish transport research (Understanding Glasgow, 2016), Glasgow vehicles had covered approximately 3.5 billion Vehicle Kilometres. Using vehicle kilometres to quantify vehicle usage and levels of traffic, it is clear that Glasgow has the highest levels of vehicle usage, closely followed by Edinburgh at approximately 3 billion vehicle kilometres. It should be noted that this is the total distance travelled of all forms of road vehicles such as cars, buses, trucks and Lorries etc. Research by Transport Scotland (2016) has also shown that 61% of Glasgow inhabitants who work away from home commute by using their own vehicle. This information serves to demonstrate the sheer volume of vehicles and vehicle usage which is so heavily relied upon in Glasgow. As things stand, there is only a small quantity of EVs in use in Glasgow, and there is a huge potential for growth if motorists are to fully adopt EVs and phase out conventional vehicles. This growth obviously has the consequence of significant demand change from fossil fuels to the electricity grid. The following sections of the literature review assess EV technology to understand specific energy and infrastructure requirements in comparison with conventional vehicles in order to improve understanding of the impact widespread EV use will have on the electricity network.

2.2 Electric Vehicles

2.2.1 EV Introduction

There are three typical electric vehicle variants available on the market and in use in the UK. Figure 2 below shows the EV configurations available (Transport Scotland, 2013). Vehicle *A* is a battery EV whereby the electric motor is driven with power supplied by a battery pack, and hence is fully reliant on plug in charge points to recharge the battery. As there is no other power source, this type of vehicle is will use the charging points more frequently, it is also the EV configuration used in this investigation.

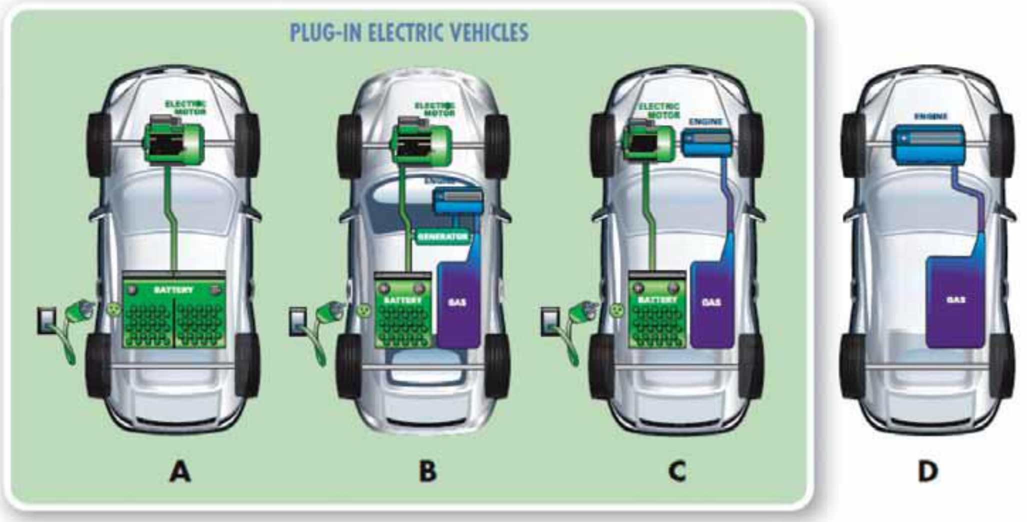

Figure 2 Electrice vehicle configurations (Transport Scotland, 2013, p. 2)

Vehicle *B* and *C* are series plug-in hybrid and parallel plug-in hybrid respectively. They both have a conventional internal combustion engine and are commonly known as Hybrid Vehicles (HV). B has the addition of a generator that can be used to top up the charge in the battery, and C does not have a generator, but instead the engine directly drive the vehicle in parallel with the electric motor in order to extend the range of the vehicle and provide power for certain speed ranges. The advantage of the hybrid vehicle (both B and C) is the increased range capability of the vehicle therefore reducing the frequency of charging requirements, thus arguably improving the practicality of the vehicle. However, as mentioned before, this investigation only considers type A as it is purely electric and has no exhaust emissions.

2.2.2 EV Performance – Range and Efficiency

A popular EV on the market today is the Nissan Leaf and according to Nissan (2016), has a range of 155 miles with a full charge. Although this is a smaller range than a motorist would expect from a conventional vehicle, it is also worth considering the comparison of energy efficiency such as the range per unit of energy as this section will investigate.

Figure 3 below from the Office of Low Emission Vehicles (2013, p. 36) shows the mileage of an electric vehicle using 1kWh of energy and comparing it with existing small sized conventional vehicles with 1kWh worth of fuel. According to the diagram, EVs are significantly more efficient per kWh than conventional fossil fuelled equivalent cars. A standard EV can cover 4.54 miles per 1kWh compared to 1.37 miles that a small diesel car can achieve. This may be considered to be very optimistic but according to EV manufactures (Nissan, 2016) (Tesla, 2016) advancements in technology, weight reduction, lower transmission losses (due to a simpler drive train), less noise and sophisticated Brake Energy Recovery (BER) systems help extend the range of the vehicles and so it can be understood why EVs have improved efficiencies. Although, as manufactures recognise (BMW, 2016) EVs have to deal with the electrical demand from the ever increasing array of electrical equipment that are standard fits on vehicles.

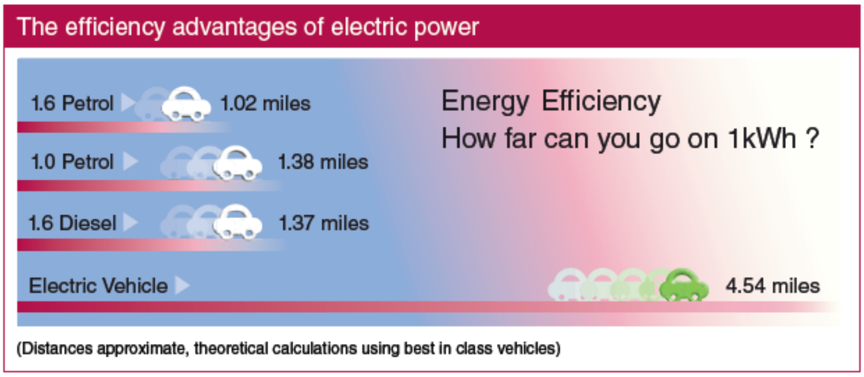

Figure 3 The efficiency advantages of EVs (Office for Low Emission Vehicles, 2013, p. 36)

However, the EV range given in Figure 3 above may still seem optimistic in comparison to a separate study conducted by the Royal Academy of Engineers (2010) where results from their EV trials show that EVs equivalent to a small conventional four-seat car use around 0.2kWh/km in normal city traffic which is approximately 3.1 miles per 1kWh. This lower mileage may be due to EV technological advancements as the two studies were conducted 3 years apart. However, it's been observed that neither study takes into account the significant power loads from vehicle heating and air conditioning systems that will have the impact of severely reducing EV range.

All-in-all, holistically looking at energy consumption and despite increasing demand from the electrical network, there is an opportunity for an overall energy saving following the widespread adoption EVs. However, this investigation deals with the impact on the electricity network only.

2.2.3 Charging Points

A charging infrastructure is required to support plug in EVs. Charging facilities must be readily available and reasonably practicable in order to maximise the convenience of using EVs and to reduce chances of being cut short when needing a top up charge. Transport Scotland (2013) envisions that the majority of charging can be done at overnight from home and would provide the majority of the charging load. However, consideration has to made regarding the need for battery top up during the day in order to increase EV range. Also, it should be recognised that many Glasgow residents do not have off street parking and as such it makes it very difficult to carry out home charging overnight and will increase their dependency on the publically available charging points.

The expectancy for publically available EV charging points will naturally match with what motorists expect in availability and infrastructure of existing fuel stations which are in use today and are heavily reliant upon.

Charging points or stations can be in a number of forms. According to the WNA (2016) there are four types of charging stations:

- Residential Charging (typically overnight);
- Parking station, with a range of types and charging speeds;
- Public fast charging with speeds greater than 40kW
- Battery Swap

This section of the literature review will provide more detail on the different charging types and the implications they would have as a consequence of widespread use.

Residential charging in Glasgow, as well as the rest of the UK, is more of a difficult to implement for all motorists due to the fact that a significant proportion of motorists live in apartments or houses which do not have garages or off the street private parking as in other countries such as the USA (World Nuclear Association, 2016). The Scottish Government recognises this issue and according to Scottish Household Survey Annual Report (2011) 66% of households in Glasgow are flats, tenement apartments or any other type of multi-dwelling unit building. This would suggest that many motorists may find it difficult to adopt the overnight residential charging method.

A majority of publically available charging stations in Glasgow are rated at 7kW or 22kW, (Glasgow City Council, 2016). Figure 4 below shows a typical charging point installed and operated by the Glasgow City Council.

Figure 4 EV Charging Point in Glasgow (McAllister, 2015)

Fast charging systems are favoured by Tesla Motors (2016), they have their own charger design known as the Supercharger as shown in Figure 5 below. Tesla is pushing to use this systems throughout the UK and have already installed many in locations such as motorway service stations, where fast charging is the more convenient option due to the need for quicker charging times. The charging stations deliver 120kW and according to Tesla, it will take only 30mins to provide enough charge the give the EV (Tesla model S and Model X) a range of 170 miles (Tesla Motors, 2016).

Figure 5 Tesla Supercharger (Tesla Motors, 2016)

The battery swap concept in theory enables an almost instant recharge, see Figure 6 below. This method of charging an EV does allow for easier management of charging loads. Such that, because a store of batteries is held at specific locations whereby charging can be centrally controlled to correspond with times of low grid energy demand, but also managed so that the supply of fully charged batteries are always available for EV users. All of which could reduce peak load loading. However, starting up the infrastructure required could be very costly and the turnover of batteries could prove logistically very difficult to manage due to the numbers involved. Also, it is difficult to exchange a battery pack in an EV and as of yet, no feasible method of doing this on a widespread scale has been developed, proven and accepted. Better Place trialled the concept and attempted to implement it, however the firm folded in 2013 due lack of interest from motorists and manufactures (Davis, 2013).

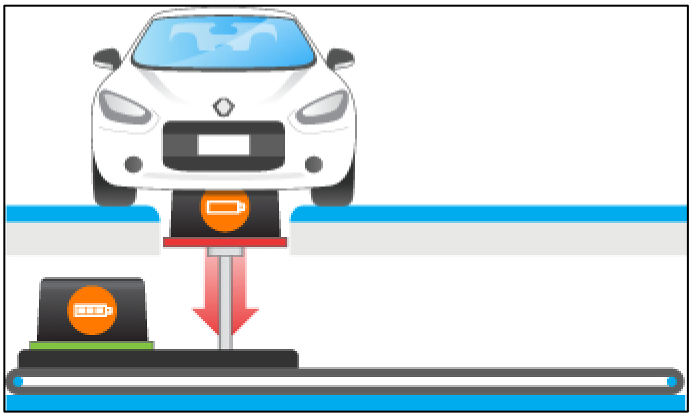

Figure 6 Battery swapping station concept (Davis, 2013)

2.2.4 Charging Capacity

At present, the on street parking points in Glasgow have charging capacities of 7kW, 22kW or 50kW and are summarised in Table 1 below (Glasgow City Council, 2016). 7kW charging points are most abundant in Glasgow, but 22kW chargers are favoured by the council for future installation. The choice of charge rates is a balance of practicability of the speed of charge from the charging point and the loading on the equipment and the electricity network, as well as being safe for used by motorists.

Charging Capacity	**Number of Charge Points**
7kW	47
22kW	30
50kW	9
All	**86**

Table 1 Glasgow City EV charging stations (Glasgow City Council, 2016)

According to Table 1 above the total number of charging points within Glasgow is currently at 86. This demonstrates that the introduction of an EV charging infrastructure is still in it's infancy in Glasgow, as in most cities. Widespread EV use would mean the majority of personal vehicles being replaced by EVs and the number of charging points significantly increasing to a scenario where charging points are available in most parking spaces on the street, car parks and multi-storey car parks.

In order to understand the benefit of charging capacities it is worth assessing their use in existing EVs. Nissan (2016) claim there Leaf EV is able to achieve a full charge within 5.5 hours using a standard charge capacity of 7kW. This charging can be done at public charging points or from home and will give the Leaf (with 30kWh battery installed) a New European Driving Cycle (NEDC) range of approximately 155 miles. Obviously different charging capacities achieve the full charge in different times. The fast charging capacity (such as 50kW) can achieve a 80% charge in just 30min. Charge Your Car provide approximate charging times for a range of charging capacities and are summarised below in Table 2 (Charge Your Car, 2016). The existing Glasgow charging point capacities are written in italics:

Charge Power	**Charging time**	**Power supply**	**Max. current**
3.3kW	6–8 hours	Single phase	16 Amps
7.4kW	*3–4 hours*	*Single phase*	*32 Amps*
10kW	2–3 hours	Three phase	16 Amps
22kW	*1–2 hours*	*Three phase*	*32 Amps*
43kW	20–30 minutes	Three phase	63 Amps
50kW	*20–30 minutes*	*Direct current*	*100–125 Amps*

Table 2 Approximate EV charging times (Charge Your Car, 2016)

Charge rates can only be approximated as time to achieving full charge is affected by the conditions such as battery temperature, age, charge status and battery type.

Rapid chargers are required to lower their charge rates once 80% charge has been achieved, and adopts a trickle charge from this point. Some vehicles even stop charging at this point.

When it is known the EV will not be in use for a while, such as overnight or during the working day between commutes, then a low charge capacity is perfectly practical in terms of time and achieving a full charge. If urgency and a faster charge rate are required then time to achieve a good charge can be significantly reduced with 50kW. However, the drawback is the increased current and power loadings.

2.3 Glasgow Low Voltage Distribution Network

This project considers the impact, mitigation measures and opportunities associated with increasing the number of EV reliant on the electricity network for charging, using Glasgow City as a case study to demonstrate ideas. From section 2.2.4 it is known that the number of EV on street charging points in Glasgow is only 65 (as of February 2016) and a further 14 installations are in progress (Glasgow City Council, 2016). It should be noted that drivers are encourage to do the bulk of their charging at home, in order to minimise load on the grid at peak times during the day. But workplace and city on street charging points are an integral part of helping to encourage motorists to convert to EVs.

This section of the report discusses the low voltage (LV) distribution in Glasgow, specifically concentrating on the existing infrastructure of substations located throughout the city; the services in which the substations supply within Glasgow; and examining typical electrical power and energy demand prior to the introduction of widespread electric vehicle use.

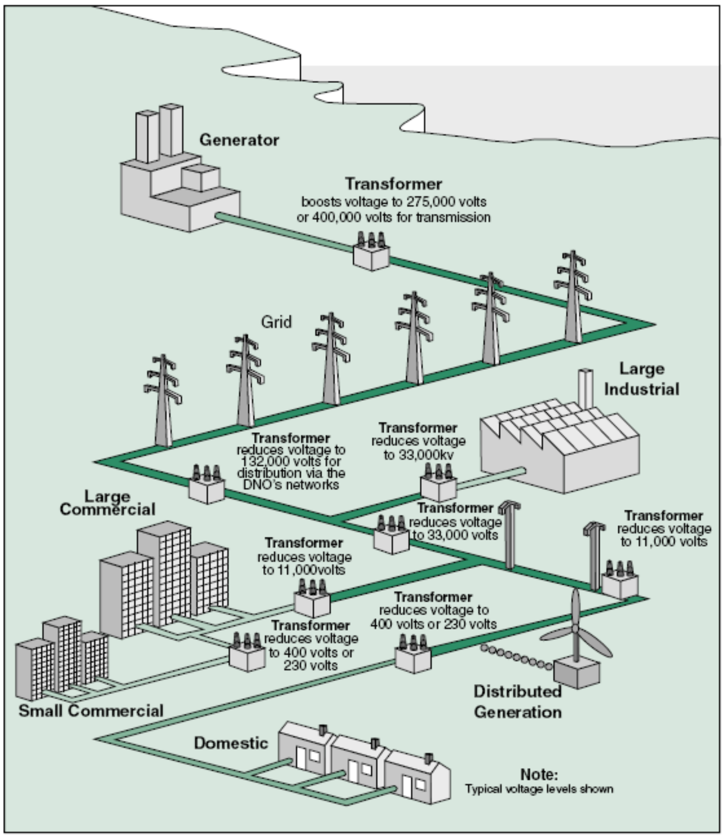

Figure 7 simplified diagram of a electricity transmission network (UK Parliament, 2010)

The diagram presented in Figure 7 (UK Parliament, 2010) shows a simplified layout of an electricity distribution network and the sequence of equipment from the power generating plant through to the end users such as housing, offices and industrial sites.

Typically, step-down transformer substations link the electricity network to the end user. A single substation can supply a number of buildings and service types. In Glasgow, there are 203 substations (in accordance with the data within the demand profile generator [DPG] tool as described in section 3.1 of this report), and they supply services such as apartments, offices, retail and leisure. Using the substation data provided in the DPG, an assessment of the total floor area of the different building types supplied by all city substations was made and presented in Figure 8 below.

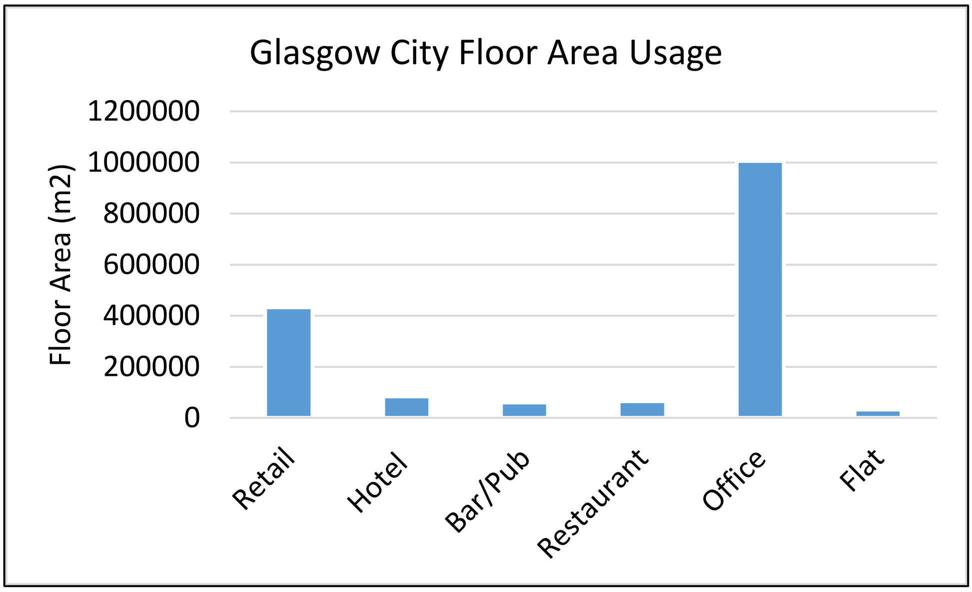

Figure 8 Total floor areas supplied by the 203 substations (from DPG described in section 3.1)

Figure 8 above clearly show that office buildings make up the greatest portion of total floor area in Glasgow at about 60% of the total. Retail is about 26%, and the remaining building type are similar ranging from only 2% to 5%. The type of building being supplied by a substation will have a significant impact on the demand characteristics, such as the demand profile of a bar will be different to an office block to the contrasting operating hours. A further assessment of the effect the building type has on the substation power demand is provided in section 4.1.

2.4 Future EV demand estimation

Using what is known from the literature review thus far, an estimation of the number of EVs that will be reliant on each Glasgow substation for charging during the working day needs to be carried out, and the method of this estimation is presented within this section of the report.

It is recognised that such a value is impossible to predict and the number of EVs a substation may supply could vary between zero and thousands (if supplying multi-storey car parks). However, a rough calculation could provide a number for widespread EV use that allows assessments to be made and conclusions to be drawn.

It should also be noted that this calculation is based upon available data regarding present day commuting habits and it is hard to say if these habits will remain or change in the future.

According to statistics available from Transport Scotland (2016), the portion of employed people in Glasgow who commute by vehicle is 41%. And according to Glasgow statistics (Understanding Glasgow, 2016) 266,600 people in Glasgow are in full time employment. Therefore, 41% of 266,600 equate to 109,306 people in Glasgow use a car to get to work. There are 203 substations in Glasgow, so 109,306 divided by 203 results in 538 EV per substation. Although due to the short average commuting distances (10 miles is the average commuting distance according to Transport Scotland (2016), 20 miles both ways) and that the majority of EV charging will be carried out at home overnight, it is assumed that the portion of EVs that will need charging during the working day time (ie between 8am and 6pm) is approximately a third. Therefore the average number of EVs that would be reliant on a single substation is to be taken as 150 approximated. Therefore, 150 EV charging points per substation is considered to be reflective on a scenario of a widespread EV use in Glasgow City and thus will be carried forward into the project mitigation strategy investigation.

In addition, it should be noted that there may be substations that supply multi-storey car parking or underground parking and will therefore supply many more than 150 EV charging points. Other substations within Glasgow City may not supply any EV charging points, or if they do it may only be a few on the road EV charging points. As said before, 150 EVs only represents a possible average. Also, the calculation does not take into account other motorists who may use a vehicle during the day such as school runs, visit to the city, public transportation, road haulage and taxis.

This investigation is only considering the electrification of personal cars and no other vehicle types. As things are, it is not clear what propulsion types will be used for heavy vehicles such as buses and Trucks. As, based on today’s technology, it is not considered suitable to have heavy vehicles purely powered by battery as the range is simply not practical. It is difficult to say which way technology will develop for heavy vehicles, but in terms of small vehicles there is a clear motive for plug in EV, therefore the bases for this study.

2.5 Network Demand and Impact of Widespread EV Use

2.5.1 UK Electricity Demand

Government statistics show that in 2014 the UK electrical energy demand was 339 TWh (Department for Business, Energy & Industrial Strategy, 2016) and the peak demand for this year was at 60 GW (National Grid, 2015). According to the National Grid electricity demand typically varies throughout the day and generally peaks at approximately 5.30pm on weekday evenings during the winter as illustrated in Figure 9 below (National Grid, 2015, p. 49). The chart shows that the peak demand is a combination of reducing industrial and commercial profile as some businesses shut down at the end of the working day whilst many people are now returning home and there is then a mass usage of appliances such as heating, kettles, TV etc.

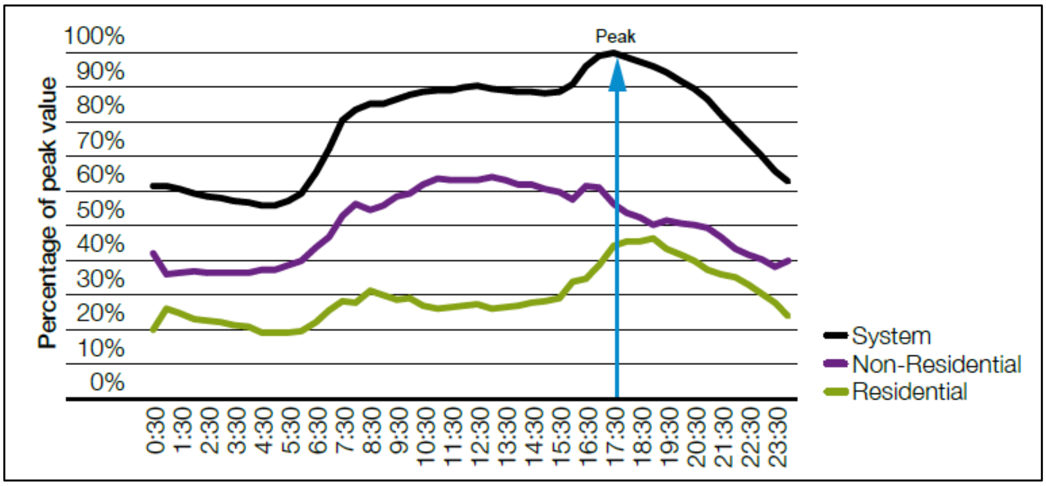

Figure 9 Typical Peak Power Demand (National Grid, 2015, p. 49)

2.5.2 Impact of Widespread EV Use

The implications of widespread EV use on the electricity grid and an urban LV network are discussed within this section of the literature review. Many studies have reviewed current electrical power demand and estimate possible future demand scenarios following the increased electrification of transportation. One such study commissioned by the National Grid and is known as the Future Energy Scenarios (FES) (National Grid, 2015). The FES presents predictions of electricity demand based on 4 scenarios ranging from no change in consumption habits to ‘Gone Green’ whereby many measures are implemented in order to meet carbon and renewable targets. Despite this, FES estimates increased electrical energy consumption for all scenarios, even the most optimistic 'Gone Green' scenario. Figure 10 below shows the estimation in the FES of the slight increase in electrical demand up to 2035 for the four scenarios (National Grid, 2015, p. 44) .

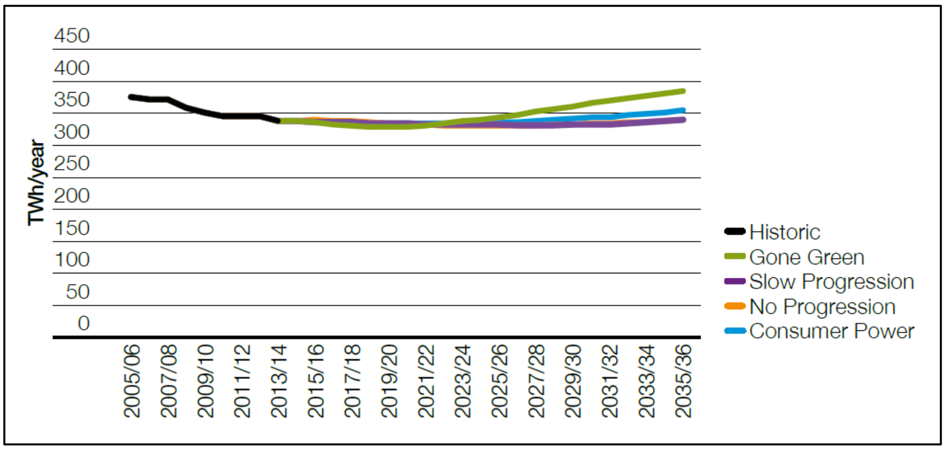

Figure 10 FES annual demand (National Grid, 2015, p. 44)

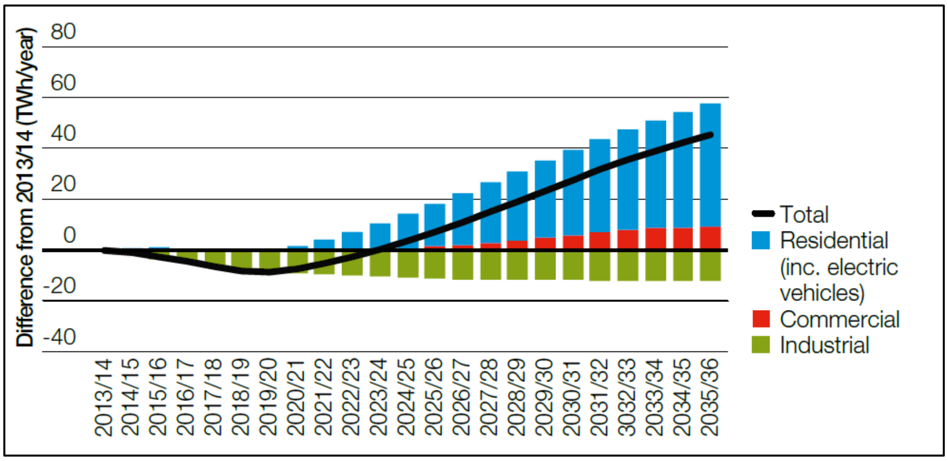

Figure 11 FES estimated 'Gone Green' power demand comparison with 2013/2014 demand (National Grid, 2015, p. 45)

Figure 11 (National Grid, 2015, p. 45) above helps to explain the apparent increased electricity demand demonstrated in Figure 10. The estimated demand increase is due to the increased residential electrical demand, of which a large portion is down to EV charging requirements. It should be noted that there is a reduction in industrial demand, but this is insignificant in comparison to the large residential demand which is believed to be caused by the electrification of heating and vehicles (the 'gone green' scenario bases this estimation on the approximation that 1 in 6 vehicles are EVs by 2035). Despite improvements in electrical efficiency due to improvements in electrical appliance technology, low energy lighting and improved building thermal insulation, these energy gains are significantly less than the increased electrical demand.

Other impacts were identified by a study of the Impact of widespread EV use in Beijing (Liu, 2012). Although Beijing is significantly larger the Glasgow, the conclusions are still relevant. The study identified that widespread EV will requires the power grid to extend its power capacity, and raises concerns that local electricity networks are going experience congestion. The major concerns associated with widespread EV use are listed below:

- The possibility of exceeding grid generation capacity at time of peak loading;
- Transformer aging;
- Disruption of power quality.

A further assessment of these points are discussed in the following three subsections.

2.5.2.1 Possibility of exceeding grid generation capacity at time of peak loading

It is easy to see why EV is going to have a large impact on electricity consumption. According to the WNA (2016) an EV covering 20,000 km per year would use 3-4 MWh/yr. In other words for every extra ten million cars an extra 30-40 TWh of electrical energy would be required from the grid. This estimation matches the FES valuation shown in Figure 11 where demand is said increase by 40 TWh.

Transport Scotland commissioned studies have shown that as things stand, 90% of EV charging is expected to take place at home, with the remaining 10% taking place at work or public charging points where available (Transport Scotland, 2013). This coincides with a study by de Hoog, et al (2013). The report shows there's a tendency to plug in EVs at peak times when returning from work. The study concludes that a 10% uptake of EV would pose risks to the network if no mitigation measures are introduced. A separate study by Huang, et al (2012) concludes that the LV network can support up to 30% penetration of EVs with 32 Amp charging systems, but this is only possible with the bulk of the charging happening overnight, as this is the time when there is more spare capacity from the electricity network. This demonstrates the importance of managing EV charging and limitations of the network. If drivers are not persuaded to charge overnight, then they are likely to plug in following their arrival home from their commute, this will add to the existing peaking demand in the early evening, and thus there is a likely risk of grid overload to beyond its capacity or power available.

2.5.2.2 Transformer Ageing

A number of studies (Dubey & Santoso, 2015) (Liu, 2012) state that the increased power and energy loading on the electricity network can have implications on transformer lifespan due to increased magnitudes between the maximum and minimum demand as well as peak loading exceeding the transformer limitations. Therefore, mitigation measures also need to consider both minimising and levelling the demand profile. The overloading of service transformers will accelerate transformer ageing and will likely increase network down time for maintenance and repair.

However, Dubbey and Santoso (2015) have also highlighted EV charging can have both a positive as well as negative affect on transformer aging. Such that, if EV charging is managed and are primarily charged during off peak hours, this would result in ‘flatter’ load profile, ie a smaller difference between the peak and minimum loads. Figure 12 (World Nuclear Association, 2016) below helps to illustrate this principle. The Flatter profile would reduce the magnitude of the cyclic expansion and contraction of the transformer, therefore potentially helping to increase the service life expectancy of the transformer.

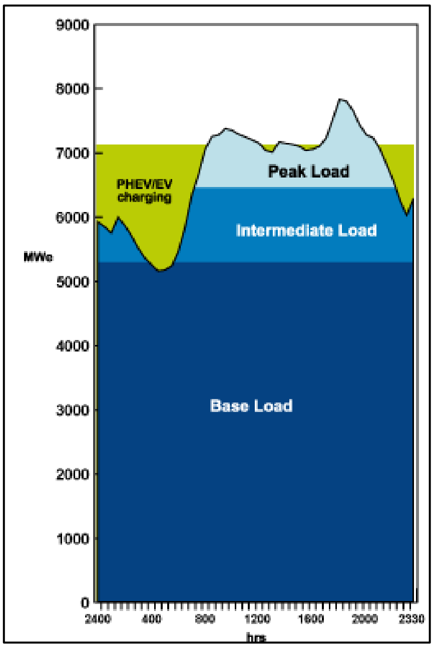

Figure 12 Load curves for typical electricity grid including overlay of EV charging demand (World Nuclear Association, 2016)

2.5.2.3 Disruption of Power Quality

The maintenance of an appropriate voltage level for customers is important to utility companies and concerns have also been raised by Liu (2012) regarding the impact on distribution power quality following the widespread adoption of electric vehicles. Concerns include under-voltage conditions, power unbalance and voltage-current harmonics. A significant power demand from a charge will significantly increase the home demand, the increased loading can lead to additional voltage drops. Other conclusions state that widespread EV charging could violate recommended limits for local distribution system wire voltage limits and cause voltage unbalance.

In conclusion, the objectives for compiling mitigation measures in order to mitigate the impact of the widespread use of EVs on the urban grid is to minimise the total power demand and manage demand with the aim of achieving an even demand profile. Some existing mitigation strategies are reviewed in the next section of this report.

2.6 Existing Mitigation Strategies

The section of the literature review examines existing studies and their research on mitigation measures in order to minimise the impact of widespread EV use on the on the electricity network. It will look into managing the EV charging load and also reducing power demand from other loads such as buildings by introducing micro generators and improving efficiency.

2.6.1 Managing EV Charging

Transport Scotland recognises the issues with peak time charging and increased EV on the electricity network and in its roadmap (Transport Scotland, 2013) it highlights the need to encourage home charging and utilise off-peak charging times. And in fact studies have shown that charging at home over night will be the preferred method (Office for Low Emission Vehicles, 2013), but there will still be need for charging in on street charging points (as discussed in section 2.2.3). Workplace charging is predicted to be the second most common charging location following home charging. The limitations of charging during work hours is that it is likely to coincides with already existing peak demand time hence contributing to peak time loading of the grid and does not encourage off-peak energy use. Many reports investigate the possibility of introducing variable tariffs to influence charging behaviour to help ensure off peak charging (Liu, 2012) (Dubey & Santoso, 2015) (Office for Low Emission Vehicles, 2013). But driver behaviour may already be influenced by the practicality of charging at home instead on relying on finding a charge point at the destination.

Dubey & Santoso (2015) also investigate introducing smart charging systems in order to prevent a second peak loading during off peak hours that may occur as a result of many EVs getting plugged in overnight. Smart charging aims to manage the charging loads so to level out the demand profile and minimise voltage drops. It is proposed that smart charging is controlled to optimise factors such as achieving an even demand profile or lower the costs to consumers. The difficulty with smart charging, as with any form of demand management, is the real world implementation of a method for dynamic monitoring and control.

2.6.2 Micro Generators

A method to minimize peak power flow from the electricity network is to explore the idea of incorporating micro electricity generators into the network infrastructure in order the supplement the electricity supply. This also ties in with the drive to introducing low carbon micro generation into the energy mix in order to help reduce CO_2 emissions. There are a number of low carbon micro generators options available that can be used for electricity generation, however not all can be considered due to the urban landscape of Glasgow. So, micro generating systems such as wind and hydro can't be considered here. Instead, this section evaluates Combined Heat and Power (CHP) and Photovoltaic (PV).

2.6.2.1 CHP

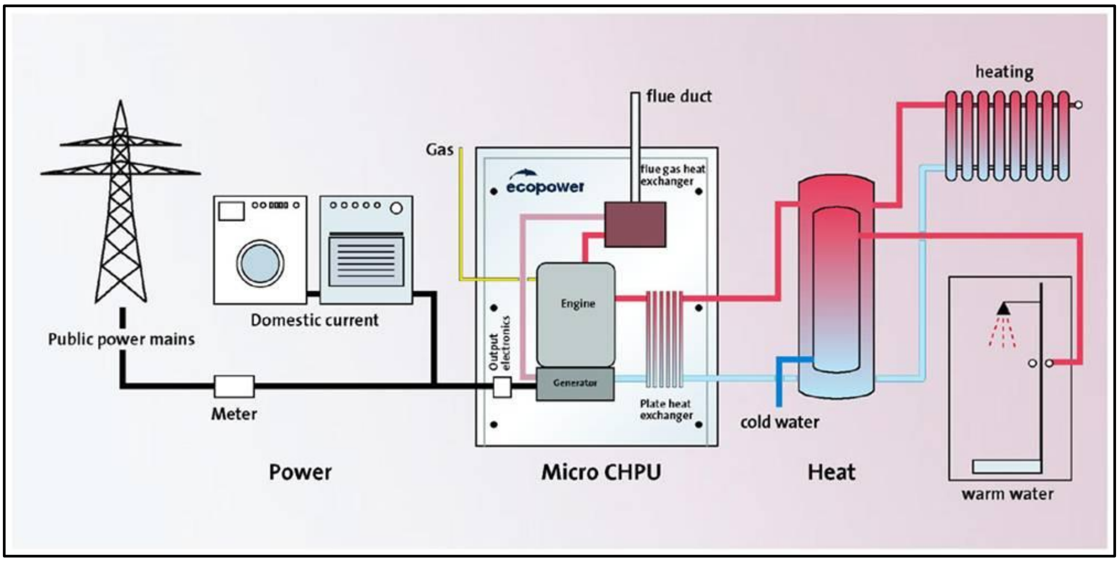

Figure 13 CHP schematic (German Power Generators)

Combined Heat and Power (CHP) systems can be installed and utilising existing gas supply and have the double benefit of generating electricity and reducing the load on the local LV network, but the waste heat can also be utilised for heating and hot water systems. The diagram shown in Figure 13 (German Power Generators) above provides a simple schematic of a typical CHP system. It is an established technology all though many are concerned with the difficulties associated with installation and the fact that it is still dependant on a gas or biomass supply, therefore have GHG emissions. However, it is widely accepted that having the 'double benefit' output means a much more efficient and effective use of the gas supply.

Sizes and types of CHP plants can vary and the suitable specification will depend upon the building or site in which the plant will supply. According to the Biomass Energy Centre (2011), commercially available plants range between 10kW and 10MW (electrical power capacity) that may be of applicable scale for integrating into an urban network. The typical ratio between heat and electrical power tend to be at 2:1 but can be as low as 1:1.

Some literature has assessed the benefit of combining CHP and Electrical Heat Pumps (EHP) to gain further energy savings, and the studies are assessed within section 2.6.3.2 of the literature review.

2.6.2.2 Photovoltaic

Typical peak electrical power demand during the day ties in with available solar energy, although the magnitude is dependent on the season and conditions. So, using PV to supplement power requirement, there is a clear possibility to help mitigate against EV charging during the day by reducing substation power demand. However, there is a limitation to the amount of PV panels that can be installed in an urban environment.

Figure 14 Installing rooftop PV panels (Photoscot, 2013)

Figure 15 Typical roof top in Glasgow city centre (Blaikie, 2016)

Figure 14 (Photoscot, 2013) and Figure 15 (Blaikie, 2016) above help to illustrate the difficulty associated with installing large PV panel areas onto urban building rooftops. This is especially the case in a city such as Glasgow where many buildings are older which have uneven roofing that may not face the optimum direction. Many rooftops also have retrofitted Heating, Ventilation and Air Conditioning (HVAC) equipment already taking up large areas making installation more difficult.

2.6.3 Improving Energy Efficiency

It has been long understood that the electricity demand of a building can be significantly reduced following improvements to the building fabric and systems in order to improve the efficiency.

A major power load on a building is heating, both space heating and for hot water. It is believed that large savings can be made by reducing the building power demands by improving heating systems such as incorporating efficient EHP systems and CHP systems.

2.6.3.1 Electrification of heating

The electrification of vehicles is not the only contributor and cause of increasing peak demand on the grid. In an urban context, migrating towards electrification of heating will help reduce dependency on fossil fuels, but will also increase the electrical power demand on the grid.

Resistance heaters my not be favoured for electrical space heating, instead many consumers will be encouraged to consider the installation of ground source heat pumps (GSHP), water source heat pumps (WSHP) or air source heat pumps (ASHP). The variants of heat pumps will be collectively described as electric heat pumps (EHP).

EHPs are favoured because the improved efficiency in comparison with resistance heaters. The efficiency and gain to be had from using a EHP is determined by the Coefficient of Performance (COP) describing the ratio of heat energy gained against the electrical power injected into the system. Various studies have been carried out determine the implication of widespread implementation of EHP installation and operation on local energy networks as well as LV networks.

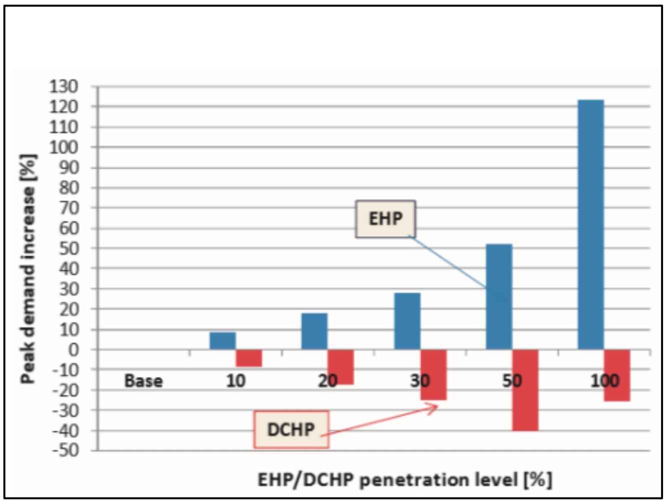

Figure 16 Peak demand for different penetrations of EHP only and CHP only scenarios (Mancarella, et al., 2011, p. 4)

A study by Manceralla, et al (2011) has shown that there is a clear danger of exceeding network limitations due to 100% implementation of electrical heating (EHP) (see Figure 16 above). In its case study for an urban context, it found that urban substations where becoming overloaded at 30% penetration and beyond. Thus concludes the need for network reinforcement. This shows the penalty associated with migrating away from conventional gas heating systems to electrification of heating, even if using more efficient EHP systems. This is of significant concern as EVs will only contribute to the problem, but the report goes further, and investigates mitigating the EHP loading by combining EHP and CHP, and will be discussed below.

2.6.3.2 Combining CHP and EHP

Reducing electrical power consumption of EHP can be achieved by combining CHP systems with EHP. Studies have been done in order to quantify what benefit is to be had and find the optimum CHP to EHP ratio. Manceralla, et al (2011) carried out a study which examines ways to overcome the additional loading caused by electrification of heating.

As discussed earlier, according to the Manceralla, et al (2011) investigation the greater the penetration of EHP the greater the peak demand increase, whereas on the other hand, the greater the penetration of CHP only, then there are peak demand reductions, as demonstrated in Figure 16 above.

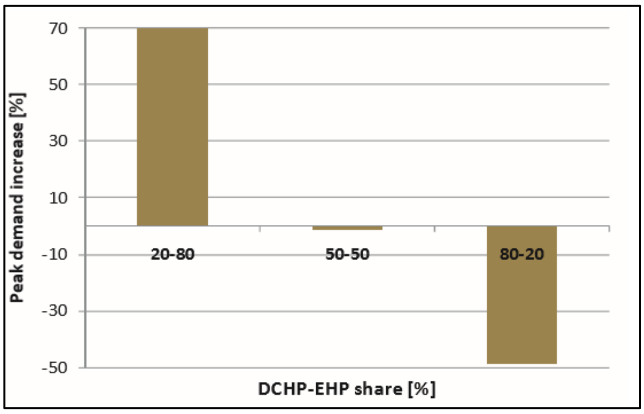

Figure 17 Peak demand for DCHP and EHP shares, 100% electro-thermal devices (Mancarella, et al., 2011, p. 4)

The study goes on to investigate combining CHP and EHP and changing the balance. Figure 17 above shows the results from the study for 20:80, 50:50 and a 80:20 CHP to EHP ratio. Note that this is 100% penetration of electro-thermal technology in the building heating system, so a 20:80 share resembles 20% of heat demand supplied by CHP and 80% from EHP. To summarise, the study shows that there is a significant peak demand increase of 70% for a 20:80 share which is in stark contrast to the almost -50% achieved by the 80:20 scenario. The 50:50 scenario was close to matching the baseline where there was no CHP or EHP installed. This shows that having a significant share of CHP provides enough power to not only compensate for EHP supply but also enough to reduce power loading even further.

It should be noted that the paper acknowledges that the main driver for the installation of systems is the environmental impact, and assessing the consequences of using more fuel for CHP against electricity with EHP is out of scope, and is not in scope of this investigation.

Knowing that introducing a significant share of CHP can significantly help reduce demand and can therefore help to accommodate increased demand from widespread EV charging, and is to be considered as a mitigation measure in this investigation.

2.6.3.3 Other Efficiency improvements

It is recognised that the substation peak demand and energy consumption can also be reduced by other methods such as making improvements to the thermal efficiency of the building fabric, introducing efficient lighting and reducing appliance demand. These are all considered and investigated (as described in section 3.1 and 3.2.4) and outcome is presented within the results section of this report (4.4).

3 Project Method

Following the literature review, a thorough understanding of the impact widespread EV charging has on the electricity network. This section of the report provides details of the project investigation methodology in order to achieve the aim of investigating and determining effective mitigation measures in order to minimise the impact. This section of the report provides a description of the Excel based profile generation tool and the investigation methodology which utilises the tool.

3.1 Dedicated Profile Generation Tool Description

An Excel based dedicated profile generation tool known as City Substation Electrical Demand Profile Generator (DPG) v1.5.6 was utilised along with a methodical investigation plan to simulate a range of substation loading scenarios with the aim effectively limiting the substation peak load demand and weekly electrical energy consumption.

The DPG tool was developed by the Energy Systems Research Unit (ESRU) at Strathclyde University in collaboration with Scottish Power. The tool allows the user to analyse the transformer substation loads by creating an inventory of building types which it supplies. The Profile Generation Tool models the power load of every substation in the city of Glasgow, of which there are 203 in the total. The demand of each substation can be changed by changing the model scenario settings.

The DPG tool uses disaggregated demand profiles generated using the ESP-r building simulation tool (also developed by ESRU) with the following available power profile sets categorised as building types:

- Retail premises;
- Domestic flats;
- Club/pub;
- Restaurant.
- Office;
- Hotel;
- EV charging;

Each of the building types listed above have the following breakdown of specific load profile types:

- Heating demand;
- Cooling demand;

- Lighting electrical demand;
- Small power loads.
- Lifts;
- Hot water;
- PV (supply);

All profiles are expressed in kW/m^2 at 0.5 hour intervals, and the floor area can be adjusted or is pre-set for existing substations. The DPG tool also allows adjustments to be made to the following settings:

- Heating and DHW;
- Lighting Efficiency;
- PV integration;
- EV numbers and charging capacity;
- Heat load shifting;
- CHP implementation;
- Appliance demand change;
- Building Efficiency.

Section 4.1 provides details of a selection of substations in order to give an example of building types, floor areas and the influence building type has on the demand profile.

The DPG tool has gone through a verification process as detailed within a report by Kelly, et al (2016). In summary, the modelling data from the DPG tool was compared with monitored data from a selection of Glasgow substations. The report concludes that despite the recognised limited input information, there was a close correlation between the modelled and historical data sets. An assessment of the average errors at each time-step for the power demand was made and was found to be less than 20%

However, as with any modelling and simulating tool, there are recognised limitations to the tool. Kelly, et al (2016) acknowledges that Poor estimations of floor area could lead to substantial discrepancies between modelled and historical data.

Nevertheless, the DPG tool is considered to be sufficiently accurate and effective in order to carry out reliable assessments and to draw firm conclusions from.

3.2 Investigation Methodology

The profile generation tool has a large amount of information stored, and equally, it is capable of generating vast volume of data associated with the 203 substations and the array of scenario settings that can be applied. Therefore, it is important that the investigation methodology is structured and focused on determining the best measures to minimise the substation electrical peak load demand and energy consumption. From which, mitigation strategies can be compiled. In order to achieve this, the method is made up of 5 sets and the sets are listed below with full explanation provided in section 3.2.1 to section 3.2.5.

- Set 1 - Base case study (normal grid operation with no EV load);
- Set 2 - EV impact study;
- Set 3 - FES ‘Gone Green’ scenario study;
- Set 4 - Sensitivity study and mitigation study;
- Set 5 - EV charging management study;
- Set 6 - Mitigation strategies.

It should be noted that all simulation runs where conducted for a Glasgow winter season as winter is considered to be the season with the largest energy demand due to increased heating requirements, therefore amplifying any differences to be analysed.

3.2.1 Set 1 – Base case Studies / Preliminary Substation Investigation

The purpose of this stage of the investigation was to assess the characteristics of the substation power demand and energy consumption and improve understanding on the effect different building types have on substation loadings. This assessment uses present day loading scenarios and a selection of Glasgow substations.

The substation selection was based on choosing substations which had a bias to each building type.

With the selected substations, profiles where generated with a base case scenario that is a reflection of the current power usage and efficiencies for heating, lighting, appliances and other loads as described in section 3.1. At this preliminary stage no EV charge load had been applied, as it is just a baseline assessment of the substation loading. The information of interest here is the breakdown of the separate loadings and how they influence the total demand. Table 3 below shows the simplified investigation matrix for set 1 of the investigation. A detailed matrix is provided with the appendix section of this report (see section 6.1.1).

Set ID	Test Name	Substation ID	Description	Scenario Setting
1_1	Retail demand profile study	sss002	Retail bias	Base case
1_2	Hotel demand profile study	sss135	Hotel bias	Base case
1_3	Bar/Club demand profile study	sss179	Bar/Club bias	Base case
1_4	Rest. demand profile study	sss002	Restaurant bias	Base case
1_5	Office demand profile study	sss171	Office	Base case
1_6	Flat demand profile study	sss153	Flat	Base case
1_7	Average substation study	AVE	All	Base case

Table 3 Set 1 investigation matrix –Base Case Study

It should be noted that 'AVE' is a custom substation created. Its loadings are based on the average floor area per substation. The substation was created for investigation purposes because it presents fair representation of substation loadings and will be used for the other sets of the investigation. Details of the Average substation are provided in section 4.1.

3.2.2 Set 2 – Adding EV Charging to Base Case Scenarios

An EV charging demand (that reflects the widespread use of EV in Glasgow City if they have been phased in and replace the majority of conventional vehicles) is applied to the 'AVE' substation, with no other changes made to the scenario. This allows an assessment of the impact of EV charging has on the existing substations load profiles. Table 4 below shows the simplified investigation matrix for set 2 of the investigation. A detailed matrix is provided with the appendix section of this report (see section 6.1.2).

Set ID	Test Name	Substation ID	Description	Scenario Setting
2_1	Impact of 0 EVs	AVE	All	Base case
2_2	Impact of 50 EVs	AVE	All	Base case
2_3	Impact of 100 EVs	AVE	All	Base case
2_4	Impact of 150 EVs	AVE	All	Base case

Table 4 Set 2 investigation matrix –EV Impact Study

3.2.3 Set 3 – EV charging Impact on a 'gone green' scenario

As well as determining the impact of widespread EV use on the electricity network loading on base case loadings, the EV charging will also be applied to network use scenarios that reflect change in how power is used from the network. In this case, the ‘gone green’ will be modelled with widespread EV use integrated. The ‘gone green’ scenario reflects a reduction in appliance and lighting demand and greater building efficiency. Table 5 below shows the simplified investigation matrix for set 3 of the investigation. A detailed matrix is provided with the appendix section of this report (see section 6.1.3).

Set ID	Test Name	Substation ID	Description	Scenario Setting
3_1	Impact of 0 EVs	AVE	All	Gone green
3_2	Impact of 50 EVs	AVE	All	Gone green
3_3	Impact of 100 EVs	AVE	All	Gone green
3_4	Impact of 150 EVs	AVE	All	Gone green

Table 5 Set 3 investigation matrix –‘Gone Green’ EV Impact Study

The gone green scenario is a reflection of the FES gone green estimation of demand (National Grid, 2015) following a realistic investment and implementation of systems and efficiency of energy supply and uses.

3.2.4 Set 4 – Scenario Sensitivity Assessment and Mitigation Assessment

This part of the study investigates possible mitigation measures. This includes a sensitivity study of making adjustments to determine which settings would provide mitigation to the large EV charging load in order to minimize the peak network.

The peak load sensitivity assessment was carried on making adjustments to heating, lighting, PV, CHP, Appliance demand and the efficiency of the building fabric.

Once the sensitivity assessment is finished, the adjustments that have made the significant and feasible load savings will be combined in order to provide mitigation solutions.

For each sensitivity assessment, feasibility of implementation of the changes is considered. For example, significantly increasing the PV supply capacity is limited by the available installation areas in an urban environment (as discussed in the literature review, section 2.6.2.2).

Table 6 below shows the simplified investigation matrix for set 4 of the investigation, including the scenario adjustments. A detailed matrix is provided with the appendix section of this report (see section 6.1.4).

Set ID	Test Name	Substation ID	Description	Scenario Setting
Electric Heating Sensitivity Study – COP 1				
4_1_1	Electric Heating - 0%-COP 1	AVE	Electric Heating	Base Case
4_1_2	Electric Heating - 25%-COP 1	AVE	Electric Heating	Base Case
4_1_3	Electric Heating - 50%-COP 1	AVE	Electric Heating	Base Case
4_1_4	Electric Heating - 75%-COP 1	AVE	Electric Heating	Base Case
4_1_5	Electric Heating - 100%-COP 1	AVE	Electric Heating	Base Case
Electric Heating Sensitivity Study – COP 3				
4_1_6	Electric Heating - 0%-COP 3	AVE	Electric Heating	Base Case
4_1_7	Electric Heating - 25%-COP 3	AVE	Electric Heating	Base Case
4_1_8	Electric Heating - 50%-COP 3	AVE	Electric Heating	Base Case
4_1_9	Electric Heating - 75%-COP 3	AVE	Electric Heating	Base Case
4_1_10	Electric Heating - 100%-COP 3	AVE	Electric Heating	Base Case
Efficient Lighting Sensitivity Study				
4_2_1	Efficient Lighting - 0%	AVE	Efficient Lighting	Base Case
4_2_2	Efficient Lighting - 25%	AVE	Efficient Lighting	Base Case
4_2_3	Efficient Lighting - 50%	AVE	Efficient Lighting	Base Case
4_2_4	Efficient Lighting - 75%	AVE	Efficient Lighting	Base Case
4_2_5	Efficient Lighting - 100%	AVE	Efficient Lighting	Base Case
EV Charging Power Sensitivity Study				
4_3_1	EV charging power 7kW	AVE	charging power	Base Case
4_3_2	EV charging power 22kW	AVE	charging power	Base Case
4_3_3	EV charging power 50kW	AVE	charging power	Base Case
4_3_4	Tesla Charge Power 120kW	AVE	charging power	Base Case
PV Installation Sensitivity Study				
4_4_1	PV installation - 0 m^2	AVE	PV installation	Base Case
4_4_2	PV installation - 5 m^2	AVE	PV installation	Base Case
4_4_3	PV installation - 10 m^2	AVE	PV installation	Base Case
4_4_4	PV installation - 15 m^2	AVE	PV installation	Base Case
4_4_5	PV installation - 20 m^2	AVE	PV installation	Base Case
CHP Installation Sensitivity Study				
4_5_1	CHP - 0% of total heating	AVE	heat to power ratio: 2	Base Case
4_5_2	CHP - 25% of total heating	AVE	CHP	Base Case
4_5_3	CHP - 50% of total heating	AVE	CHP	Base Case
4_5_4	CHP - 75% of total heating	AVE	CHP	Base Case
4_5_5	CHP - 100% of total heating	AVE	CHP	Base Case
CHP Installation Sensitivity Study (adjusting heat to power ratio)				
4_6_1	CHP heating to power ratio:1	AVE	CHP	Base Case
4_6_2	CHP heating to power ratio:2	AVE	CHP	Base Case
4_6_3	CHP heating to power ratio:3	AVE	CHP	Base Case
4_6_4	CHP heating to power ratio:4	AVE	CHP	Base Case
CHP and EHP Share Sensitivity Study				
4_7_1	CHP and EHP 20:80	AVE	CHP and EHP	Base Case

Set ID	Test Name	Substation ID	Description	Scenario Setting
			combined	
4_7_2	CHP and EHP 50:50	AVE	CHP and EHP combined	Base Case
4_7_3	CHP and EHP 80:20	AVE	CHP and EHP combined	Base Case
Shift Heating Loads				
4_8_1	shift loads - base case – no shift	AVE	shift heating loads	Base Case
4_8_2	shift 10% heating back 1hrs	AVE	shift heating loads	Base Case
4_8_3	shift 20% heating back 1hrs	AVE	shift heating loads	Base Case
4_8_4	shift 30% heating back 1hrs	AVE	shift heating loads	Base Case
4_8_5	shift 40% heating back 1hrs	AVE	shift heating loads	Base Case
4_8_6	shift 10% heating back 2hrs	AVE	shift heating loads	Base Case
4_8_7	shift 20% heating back 2hrs	AVE	shift heating loads	Base Case
4_8_8	shift 30% heating back 2hrs	AVE	shift heating loads	Base Case
4_8_9	shift 40% heating back 2hrs	AVE	shift heating loads	Base Case
4_8_10	shift 10% heating back 3hrs	AVE	shift heating loads	Base Case
4_8_11	shift 20% heating back 3hrs	AVE	shift heating loads	Base Case
4_8_12	shift 30% heating back 3hrs	AVE	shift heating loads	Base Case
4_8_13	shift 40% heating back 3hrs	AVE	shift heating loads	Base Case
4_8_14	shift 40% heating back 3hrs, 0% penalty	AVE	shift heating loads	Base Case
4_8_15	shift 40% heating back 3hrs, 10% penalty	AVE	shift heating loads	Base Case
4_8_16	shift 40% heating back 3hrs, 20% penalty	AVE	shift heating loads	Base Case
4_8_17	shift 40% heating back 3hrs, 30% penalty	AVE	shift heating loads	Base Case
Appliance Demand Sensitivity Study				
4_9_1	Appliance Demand 0% reduction	AVE	Appliance dem.	Base Case
4_9_2	Appliance Demand,10% reduction	AVE	Appliance dem.	Base Case
4_9_3	Appliance Demand,20% reduction	AVE	Appliance dem.	Base Case

Set ID	Test Name	Substation ID	Description	Scenario Setting
4_9_4	Appliance Demand, 30% reduction	AVE	Appliance dem.	Base Case
4_9_5	Appliance Demand, 40% reduction	AVE	Appliance dem.	Base Case
4_9_6	Appliance Demand, 50% reduction	AVE	Appliance dem.	Base Case
Building Efficiency Improvements Sensitivity Study				
4_10_1	Improve Building Eff. 0%	AVE	Imp. Building eff.	Base Case
4_10_2	Improve Building Eff. 20%	AVE	Imp. Building eff.	Base Case
4_10_3	Improve Building Eff.40%	AVE	Imp. Building eff.	Base Case
4_10_4	Improve Building Eff. 60%	AVE	Imp. Building eff.	Base Case
4_10_5	Improve Building Eff. 80%	AVE	Imp. Building eff.	Base Case
4_10_6	Improve Building Eff. 100%	AVE	Imp. Building eff.	Base Case

Table 6 Set 4 Investigation Matrix - Sensitivity and Mitigation Study

3.2.5 Set 5 – Management of EV charging schedules

The literature review section of this report provided information of schemes to promote distribution of EV charging and avoid drivers charging their vehicles at the same time hence reducing the peak load on the network. Such schemes include tariff schemes where charging rates is determined by the grid loading at a specific time.

The EV charging demand in the DPG tool is managed by a Visual Basic coding that dictates a charging probability throughout the day. It determines the chance of an EV taking charge at a particular time in the day. The default model set up allows a concentration of charging between approximately 8am and 11am, this concentration of charging contributes to the magnitude of substation peak power demand (as discussed in section 4.2).

It is considered that managing EV charging to ensure more evenly distributed charging throughout the day will reduce the peak demand. Therefore, in order to model EV charging management, the coding was changed so that charging was evenly distributed throughout a range of time periods.

The purpose of changing the EV charging distribution was to investigate the affect re distribution of the charging demand, the total charging demand for 150 EV remains the same, but there is less peaking and improved distribution which may be promoted by incentive schemes such as TOU as discussed in the literature review section of this report.

Table 7 below shows the simplified investigation matrix including the scenario adjustments. A detailed matrix is provided with the appendix section of this report (see section 6.1.1).

Set ID	Test Name	Substation ID	Scenario Setting
5_1	Original Prob. Curve	AVE	Base Case
5_2	Constant charging probability between 6 and 12 hrs	AVE	Base Case
5_3	Constant charging probability between 6 and 14 hrs	AVE	Base Case
5_4	Constant charging probability between 6 and 16 hrs	AVE	Base Case
5_5	Constant charging probability between 6 and 18 hrs	AVE	Base Case
5_6	Constant charging probability between 6 and 20 hrs	AVE	Base Case
5_7	Constant charging probability between 6 and 22 hrs	AVE	Base Case
5_8	Constant charging probability between 6 and 24 hrs	AVE	Base Case

Table 7 Set 5 Investigation Matrix – Study on Managing EV Charging Load

3.3 Mitigation Strategies Outcome

From the outcome of the sensitivity studies, mitigation strategies will be compiled. The mitigation measurements will be in the form of two possible strategies that can be implemented. One is the best case strategy (using best performing settings from the sensitivity study), the other being a feasible strategy. The feasibility of these mitigation strategies will be assessed by reviewing the following three points of interest typically associated with project feasibility:

- Cost
- Technical
- Environmental

It should be noted that there feasibility of a strategy is very dependent on the type of building and the age of the building as this could significantly influence the cost of the implementing the mitigation strategy. This is a significant consideration for a city such as Glasgow due to the diverse age range of architecture and infrastructure.

A comparison of substation peak electrical power demand and weekly energy demand will be made between the Mitigation, Base Case (Set 2) and Gone Green (Set 3) scenarios.

Table 8 below shows the simplified investigation matrix for set 4 of the investigation, including the scenario adjustments. A detailed scenario matrix with details of mitigation measures is provided with the appendix section of this report (see section 6.1.6).

Set ID	Test Name	Substation ID
6_1	Best Mitigation Scenario	Ave
6_2	Feasible Mitigation Scenario	Ave

Table 8 Final Mitigation Strategies

4 Results Assessment

4.1 Set 1 - Base case assessment of typical substation types

As discussed in section 3.2.1, the purpose of this part of the investigation is to run assessments of a selection of Glasgow city substations in order to examine the breakdown of demand profiles for the different services that make up the total demand.

The selection of substations for this part of the investigation is based on the substation supplying a particular type of floor area, i.e. retail or restaurants. From the 203 Glasgow substations available for assessment, six were selected and the selection is presented in Table 9 below:

	Floor Area					
	Office (m^2)	**Hotel (m^2)**	**Restaurant (m^2)**	**Pub/club (m^2)**	**Retail (m^2)**	**Housing (m^2)**
SSS099	1941	0	2274	0	66107	80
SSS135	0	7337	0	0	0	0
SSS179	81	0	0	7339	3468	480
SSS002	0	0	3584	0	0	80
SSS171	45661	0	0	0	0	80
SSS153	0	0	0	0	0	960
Average Substation	4956	413	323	296	2131	163

Table 9 Selection of six Glasgow city substations and average substation floor area breakdown

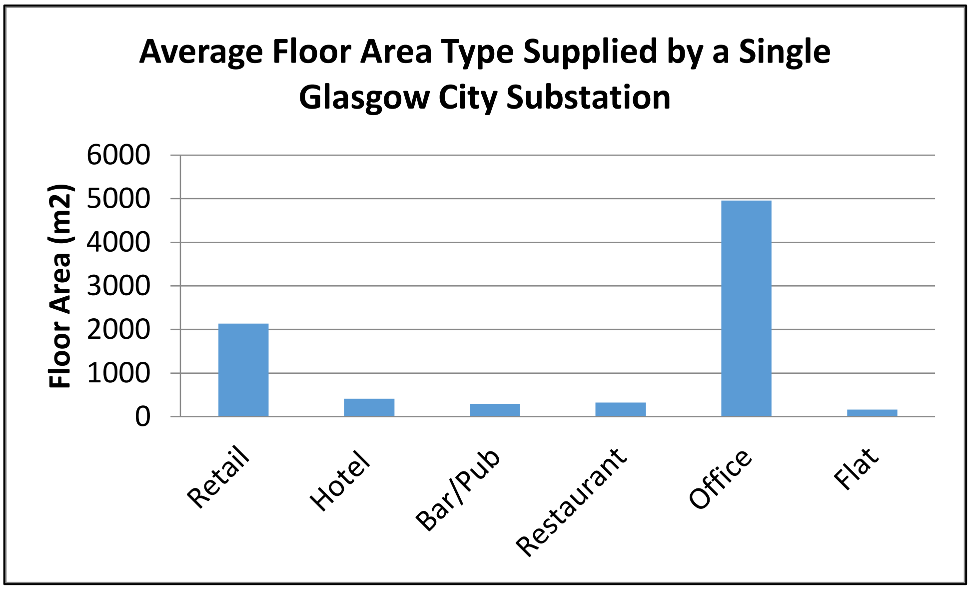

Figure 18 Average floor areas supplied by a single substation (DPG, section 3.1)

As well as showing the selection, the table also includes an Average Substation which is representative of the average floor areas supplied by all 203 substations (also see Figure 18 above). The substation was created for investigation purposes because it presents fair representation of substation loadings and will be used for the other sets of the investigation (Set 2, 3, 4 & 5).

Figure 19 shows a breakdown of floor area type supplied by all 203 Glasgow City Substations. It is clear that office space has the greatest floor area at 60% and bars/pubs makes up the smallest floor area demand on the substations at only 3%.

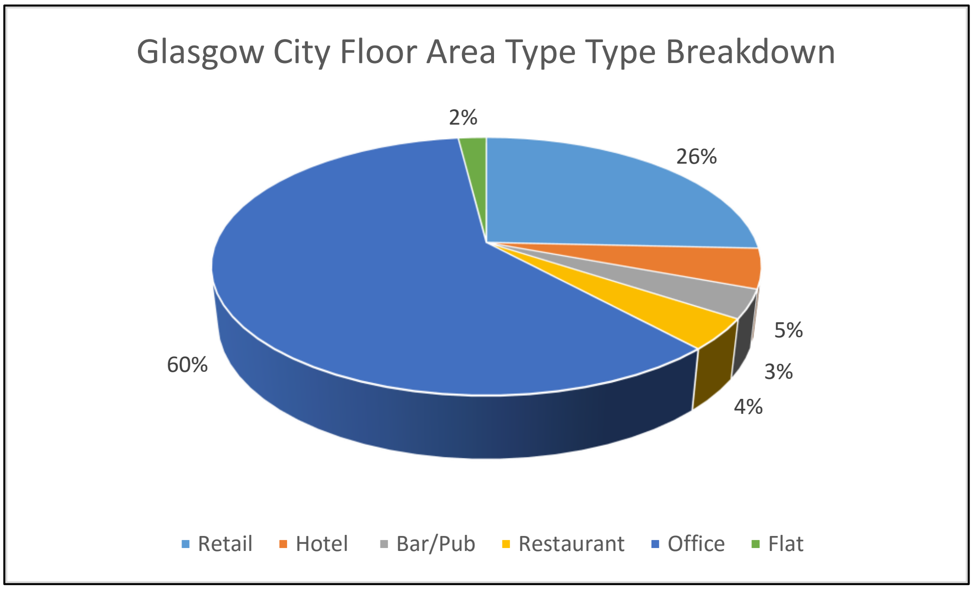

Figure 19 Pie Chart of the breakdown of floor area types supplied by Glasgow city substations (DPG, section 3.1)

It should be noted that at this stage of the investigation, peak power demand and weekly energy demand are not of interest; instead it is the demand profile form (not value) that is of particular interest. This is in order to understand the services influencing the substation electricity demand. The six substation power profiles are presented over 48 hours (2 days) in order to allow a clear assessment of the demand profiles.

4.1.1 Retail Substation

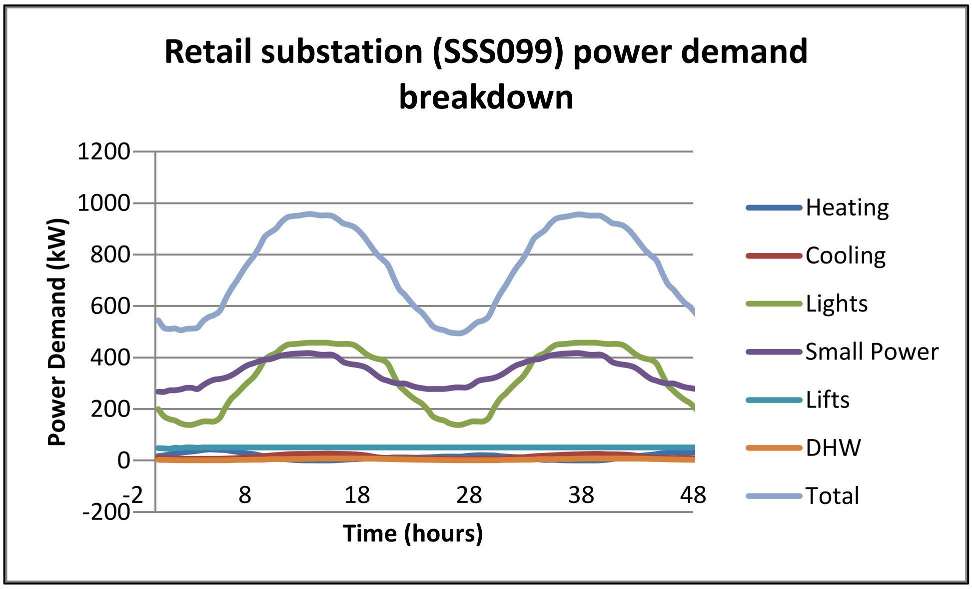

Figure 20 Retail substation breakdown of power demand over 2 days during winter

Figure 20 above presents the breakdown of electrical power demand for a substation which mainly feeds a retail floor area. The graph shows the total demand fluctuates as expected. The demand peaks during the daytime which coincides with shopping times during the week. The demand then significantly reduces by approximately 50% during the evening coinciding with closing hours.

The total demand profile is derived is from accumulation of the individual services such as heating, lighting, etc (as shown in the legend of Figure 20). The clear significant contributors to the total demand are the small power devices and lighting. This is of no surprise as good lighting is important for retail which typical use a large volume of bright lighting over large floor areas. Small power appliance make up the other services typically used in a retail environment, such as computing, communication devices, sound, displays, security and product demonstrations.

The minor contributors to the total demand are the lifts, heating, DHW and cooling. This can explained by the fact that lifts use is over a small proportion of the floor area and are not in constant use. DHW is typically not needed in retail, and there is very little requirement for cooling during the winter season. There is also a very small heating demand, but this may be due to the fact that only a small portion of heating is electrically supplied. Instead heating is typically supplied by gas boiler central heating.

4.1.2 Hotel Substation

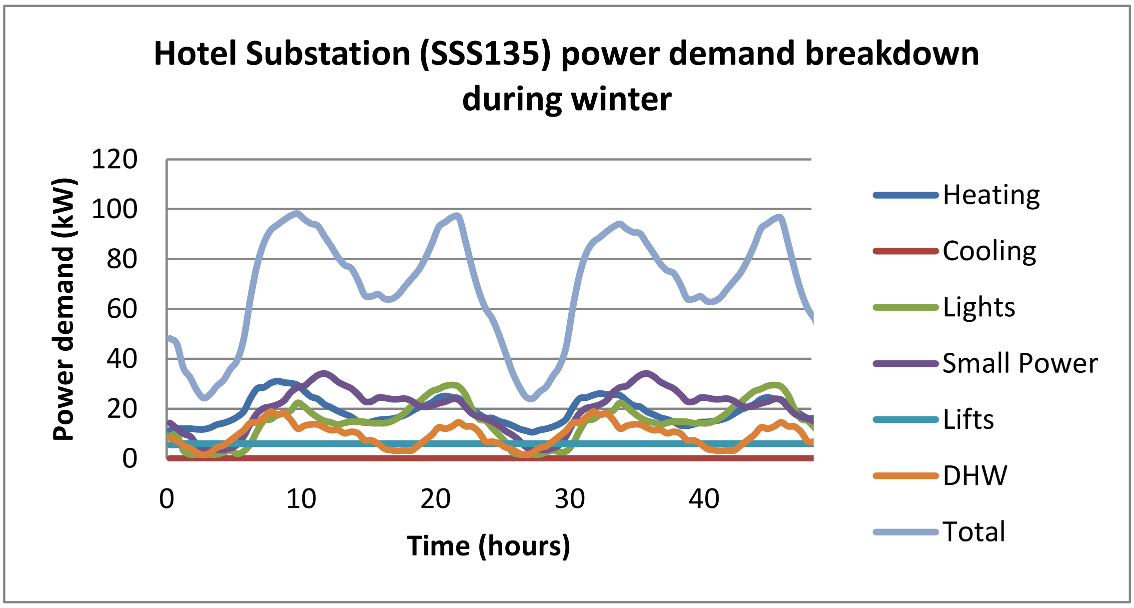

Figure 21 Hotel substation breakdown of power demand over 2 days during winter

Figure 21 above presents the breakdown of electrical power demand for a substation which mainly feeds hotel floor areas. The total demand profile fluctuates from low values during evening hours but rise earlier in the day to peak values during the evening.

It is clear from Figure 21 that there are many significant contributors to the total power demand for a substation that mainly supplies hotel services. Small power appliances will be in frequent use within hotels as shown on the graph and appears to be the largest contributor of power demand. This would be expected as hotel rooms will have appliances such as televisions, kettles and other facilities that may be in use during the day as well as hotel services, catering equipment, housekeeping and laundry operations. Lighting is another significant contributor to the energy demand. DHW is also a vital service win a hotel and there is a clear demand during the morning and evenings for showers, washing and catering facilities.

The lull in hotel demand appears to be during the very early morning hours, typically between 2am and 5am.

4.1.3 Pub/Club Substation

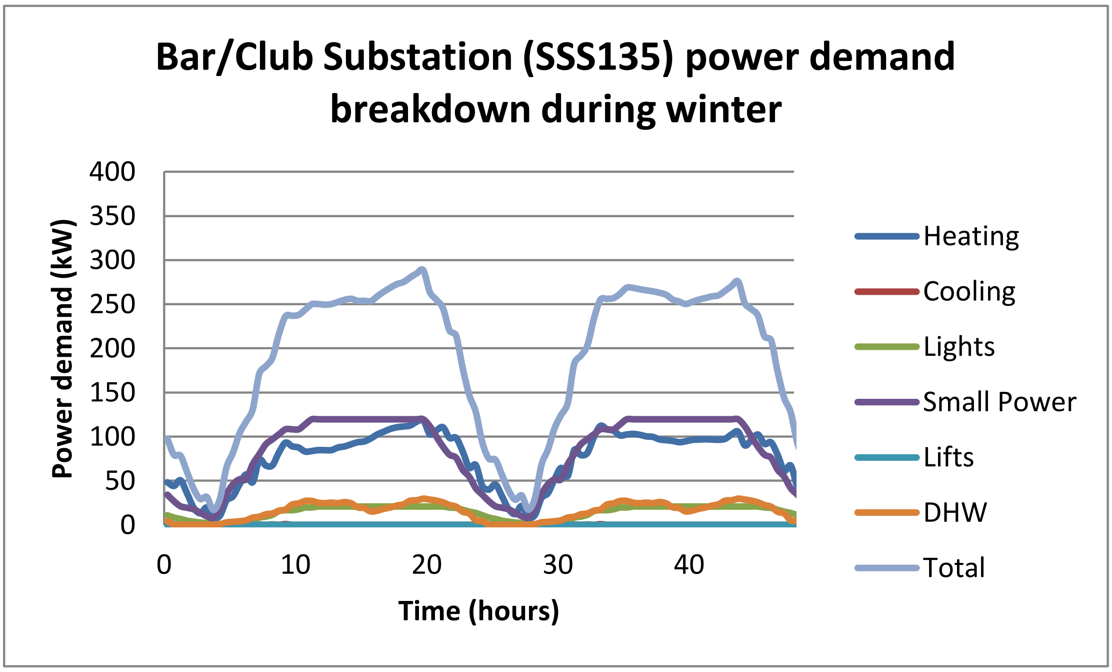

Figure 22 Bar/Club substation breakdown of power demand over 2 days during winter

Figure 22 above presents the breakdown of electrical power demand for a substation that feeds bar and clubs type floor area, and demonstrates the contribution each of the services has on the total demand.

Bar and clubs tend to operate during the evenings and through to the early morning and some open for customers around midday. Figure 22 above reflects these operating times as the power demand lull is shown to typically occur at approximately between 3am and 5am, after which the demand increases which is due to staff preparing premises for the day by cleaning, prepping food and drinks, maintenance and etc. This ties in with the fact the major contributor is small power appliances and heating systems. Evening demand will be due to music systems, bar and kitchen facilities.

Minor service demands are the lighting and DHW, again this is to be expected as lighting is typically dim in nightclubs and bars. Also, DHW would only be required for cleaning and washing up.

The peak demand occurs at approximately 8pm which is considerably later than the over floor types which again demonstrates that the floor type influences total demand profile of any giving substation. Other systems such lifts are not common in bars and clubs and therefore do not significantly contribute to the total demand.

4.1.4 Restaurant Substation

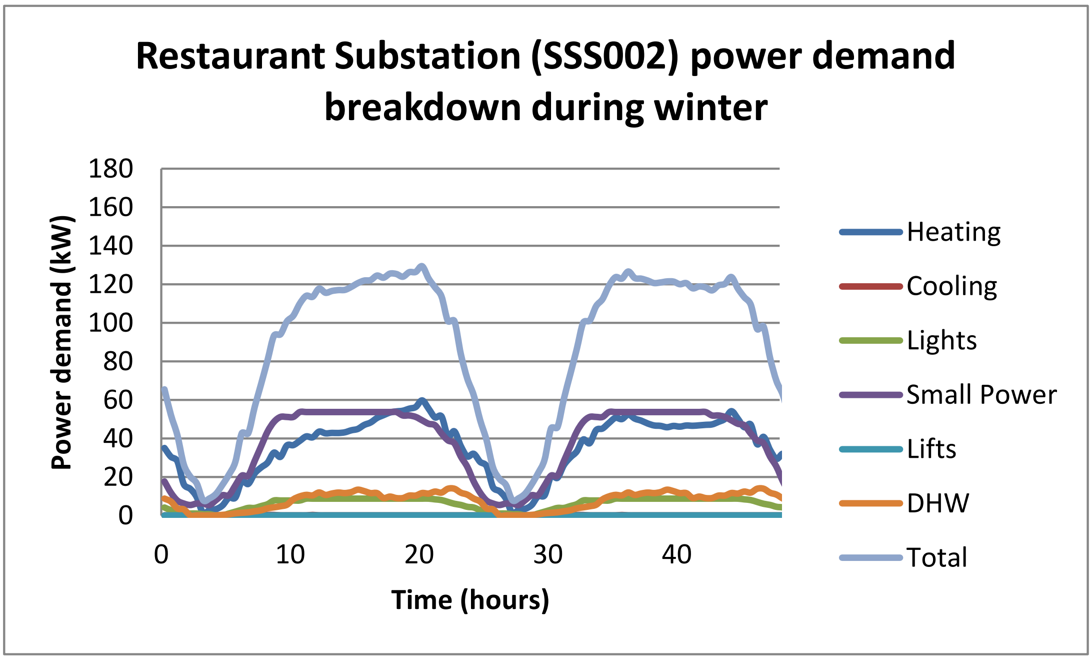

Figure 23 Restaurant substation breakdown of power demand over 2 days during winter

The restaurant specific substation demand profile breakdown is shown in Figure 23 above. The restaurant substation is very similar to the bar and club substation demand profile (assessed in section 4.1.3). Not only is the total profile almost an exact overlap, but the contribution demand profile from heating, lights, small power appliances and DHW also have similar profiles.

Restaurants, like clubs and bars, typically have different operating hours compared with other floor types. They both tend to have longer operating time frame during the day and last later into the evening and early morning, this is reflected in the total power demand profile presented in Figure 23 above.

4.1.5 Office Substation

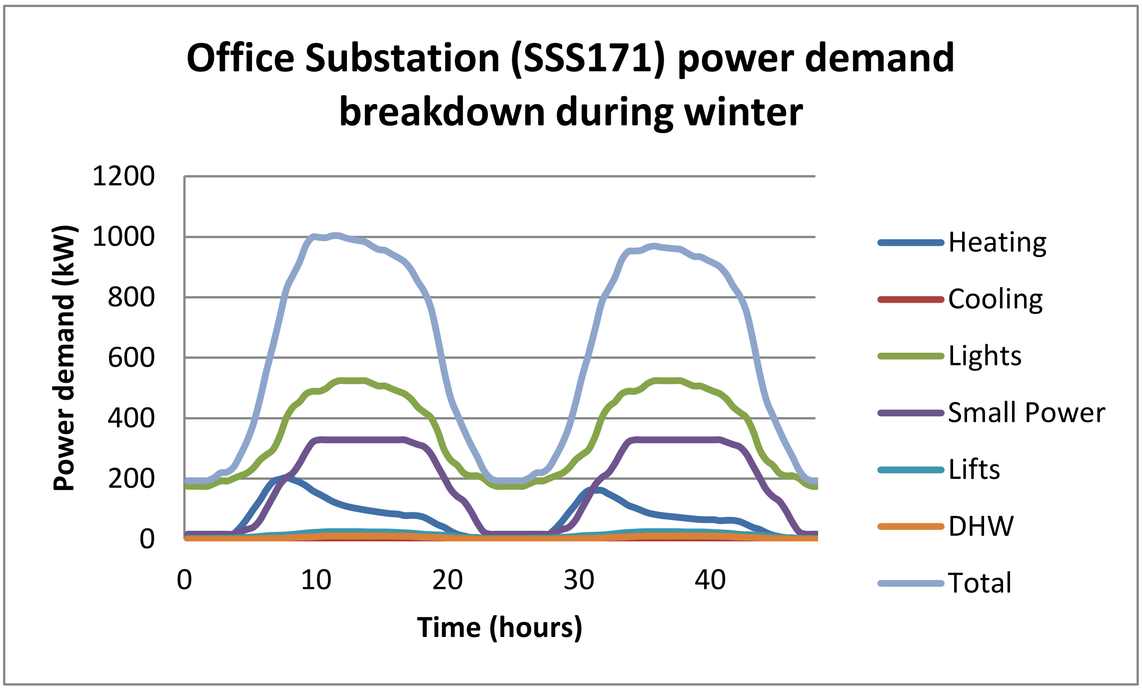

Figure 24 Office substation breakdown of power demand over 2 days during winter

The office specific substation demand profile breakdown is shown in Figure 24 above. The total demand profile peaks during the working day, which is approximately between 8am and 6pm. This ties in with typical day time working hours. The high working day demand is predominately made up of lights and small power appliances. This is to be expected as office spaces do require high levels of suitable lighting and the have many appliances in operation at any one time. Most notable are computers, printers, and other IT equipment.

Another contributor to the office substation power demand is heating, however heating peaks earlier in the working day to get the office environment up to suitable temperatures. Afterwards, less power is needed to maintain a suitable working environment due to habitation heat of lighting and passive solar thermal energy. Lifts and DHW have very minimal contribution to the office total power demand.

4.1.6 Housing Substation

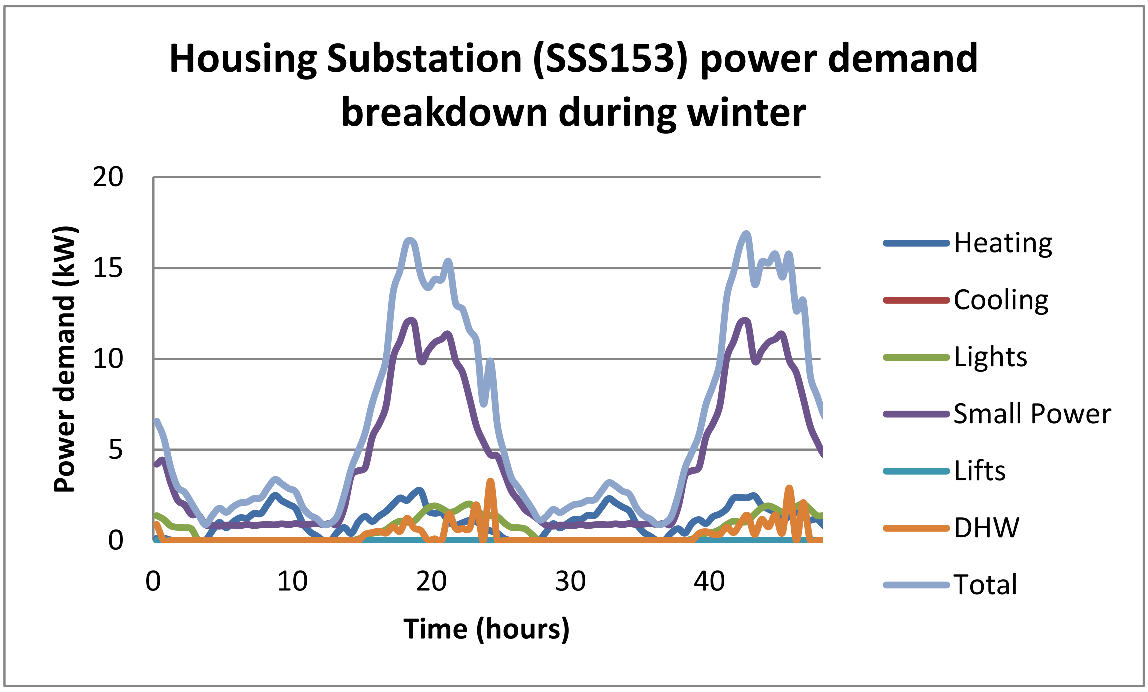

Figure 25 Housing substation breakdown of power demand over 2 days during winter

The housing electrical demand profile (see Figure 25) peaks during late afternoon and early evening. This is predictable, as it ties in with people returning home from work and schools. The most significant power load is from small power appliances. In housing this could be a large range of devices such as kitchen appliances, PCs, TVs, radios and washing machines. For most of the day these devices are switched off, as indicated by the levelled profile during working hours. Devices which are permanently on such a refrigerators are the reason why small power demand does not lower to 0 kW.

Some housing or apartments are also reliant on electrical heating systems especially during winter, and again this is represented in the graph above. However, electrically supplied heating systems are at this case (Base Case scenario) considered to be a minor contributor to total demand.

Homes typically use less lighting than retail and office environments. Hence, the lighting is used during the evening but only makes up a small portion of the overall demand. Flats are also reliant on DHW and again this contributes to overall loading during evening.

Again, cooling is not typically required during the winter, and lifts although are common in apartment blocks, are not frequently load and hence do not contribute a significant power load towards the overall demand.

4.1.7 Average Representative Substation Assessment

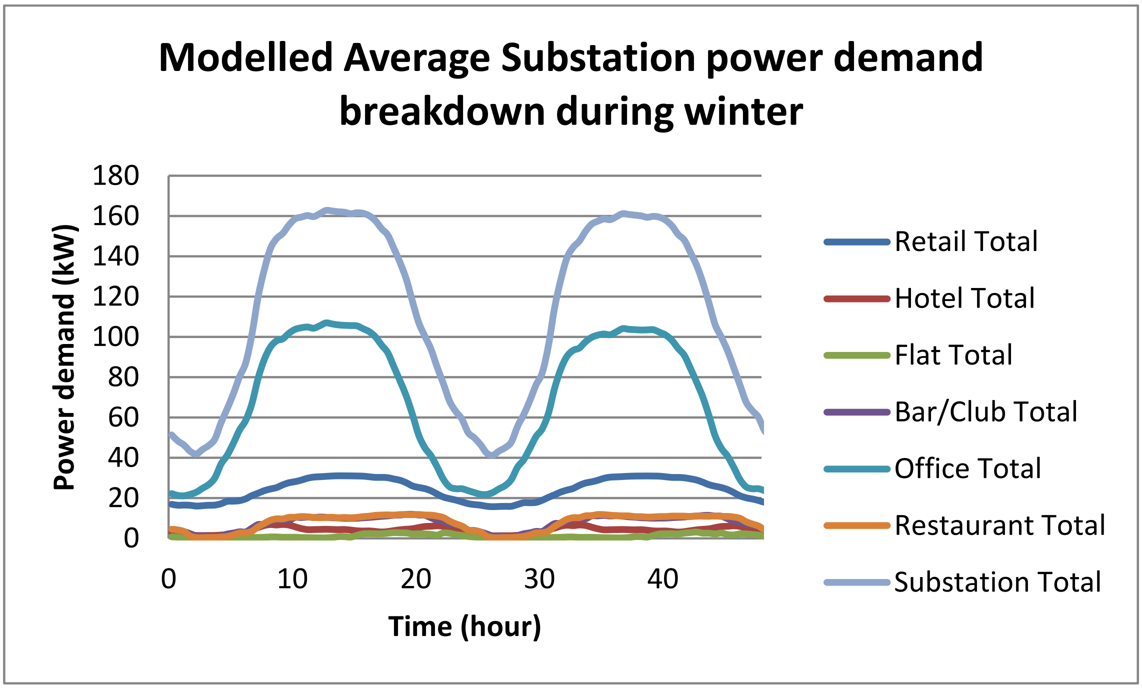

Figure 26 'Average' substation - breakdown of power demand over 2 days during winter

As explained in section 3.2.1 and 4.1, a substation was modelled that represents the average substation. The average substation is set up so it supplies the average floor areas of each floor types. It allows a proportional assessment of the different types of buildings on the overall power demand of the city.

The profile in Figure 26 above shows that demand oscillates from peak during working hours to lulls during evening and early morning hours. The peak loading appear to last for approximately 8 hours coinciding with typical working hours. It is also clear that the greatest contribution to Glasgow substation peak loading is from supplying offices. But this would be expected as office space makes up the largest portion of the total floor area in Glasgow city.

The concern with the peak timings is the issue that EV charging will further increase peak demand as the timing coincides with drivers arriving at the place of work and plugging in their EVs for charging.

The demand lull times are of significance here as these are the timings perhaps most suitable timings in which to introduce widespread vehicle charging. This will also provide the additional advantage of levelling the total demand profile thus reducing the cyclic loading on the substation transformers.

4.2 Set 2 - Assessment of Widespread EV Use

This section of the investigation is a sensitivity study to determine the implication of increasing the number of EVs has on the substation peak power demand and weekly energy demand. From the calculation presented in 2.4 of the literature review, an estimation of 150 EVs on average could be reliant on each substation. In order to determine the relationship between EVs and power demand, 0, 50, 100 and 150 was applied to the average substation and base case scenario (details provided within section 3.2.1). The results of substation peak power demand and total energy demand over a week long period during a winter season are presented in Figure 27 and Figure 28 below respectively.

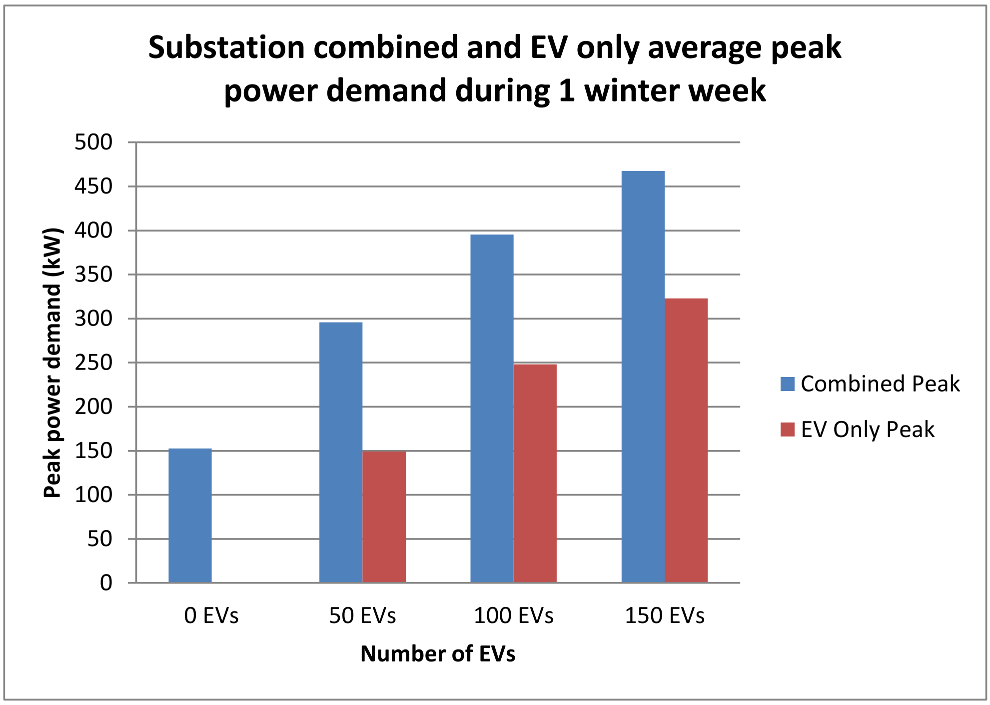

Figure 27 Impact of introducing widespread vehicle use on the ‘average’ substation peak power demand during 1 winter week

Figure 27 above shows the effect of increasing the number of EV utilising the substation has on the substation peak power from 0 EVs to 150 EVs using. The chart also shows the peak power demand contribution from EV charging only on the substation.

Predictably, the impact of introducing an EV charging load on the peak power is to increase the peak power demand, and when 50 EVs are dependent on the substation for charging, the peak power demand increased by over 100%. A further increase of similar magnitude occurs following the introduction of 100 EVs onto the substation. However, there is an apparent decrease in the peak demand by approximately 20kW when there are 150EVs reliant upon this substation for charging. This slight decrease is not clearly understood as well as not being entirely expected, but it may the result of how the software distributes vehicle charging loads. It does not necessarily mean there is less total power being delivered as will be made clear in the assessment of the energy demand below.

Overall, the apparent impact of having no EVs reliant on a substation for charging and 150 EVs is approximately 330kW which is an increase of 203%. This is a significant increase and a substantial increased load on the substation and electricity distribution network and supply systems.

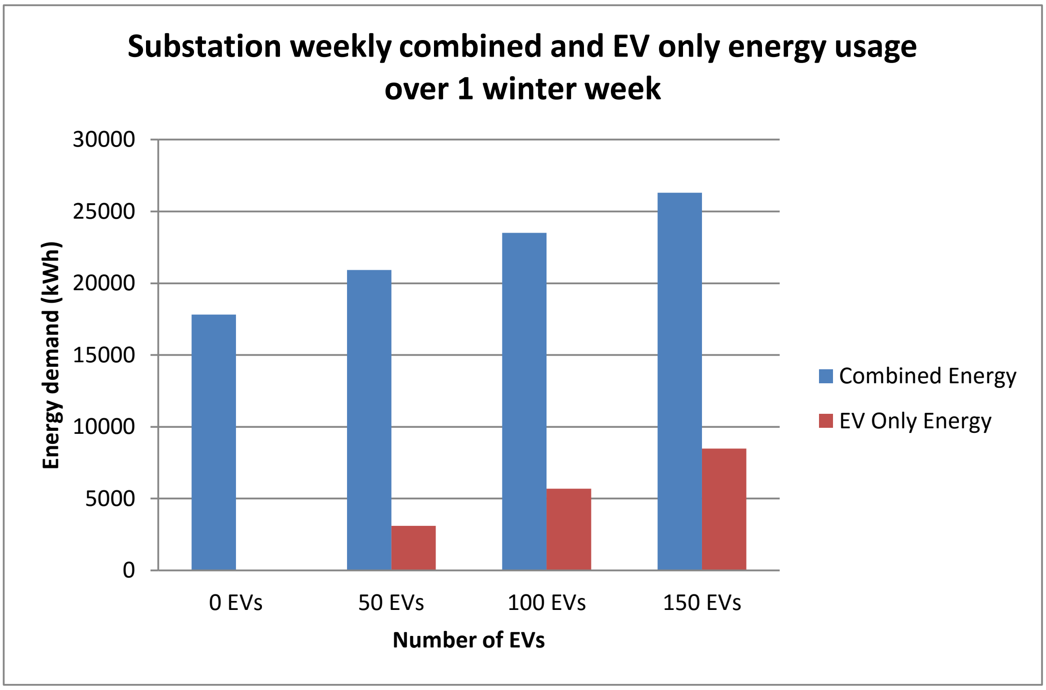

Figure 28 Impact of introducing widespread vehicle use on the 'average' substation energy demand during 1 winter week

Figure 28 above presents the energy consumption of the substations for a range of a number of EVs reliant on the substation for charging. The chart also shows the EV only element of energy consumption over a winter week.

As expected, the chart shows an increase in energy consumption as the number of EVs reliant on the substation for charging supply increases. But the proportional increase is not as great as the effect on the peak power demand.

With no EVs, the energy demand is approximately 18 MWh for the full week duration, and increases to 21 MWh with the introduction of 50 EVs. This equates to approximately 17% energy demand increase. When 150 EVs are reliant on the substation supply for charging, the energy demand for the full week is approximately 26 MWh which is a 44% increase in weekly energy demand.

The chart in Figure 28 also shows the EV element of energy consumption for each scenario, whereby 150 EVs requires approximately 8.5 MWh every week.

It is clear from the energy consumption assessment that the widespread use of EVs, if vehicle habits and usage remains the same as it is for conventional vehicle use, will have a significant impact on energy demand from the substation and supply from the electricity grid. As mentioned, before the estimated impact will be a 44% increase in electrical energy demand if the estimated average of 150 EVs are reliant on every Glasgow city substation.

4.2.1 EV charging power demand profile

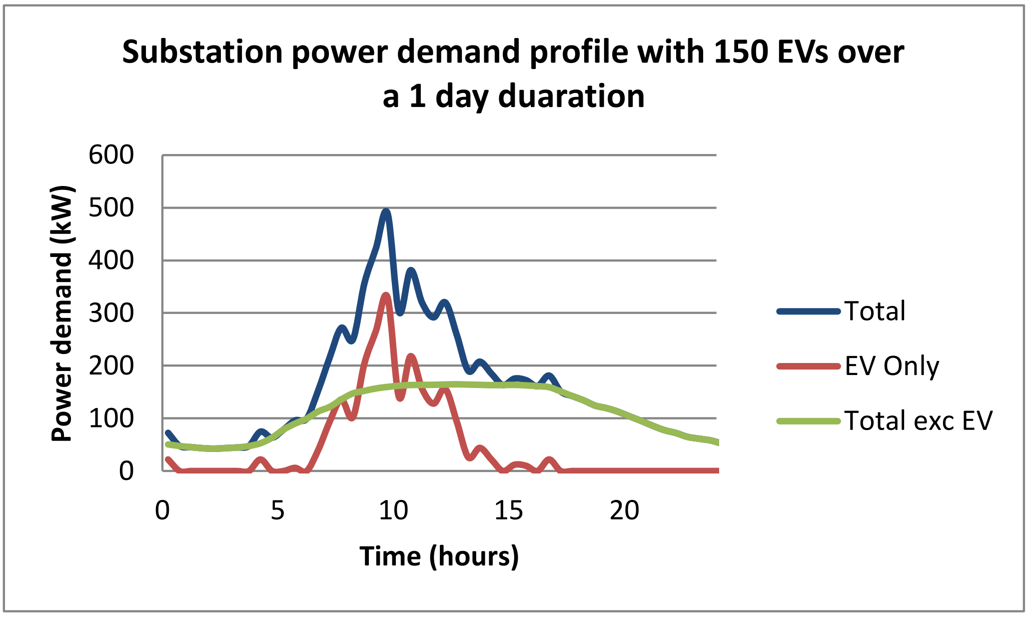

Figure 29 Impact of introducing widespread vehicle use on the 'average' substation daily power demand profile

Figure 29 shows the substation power demand with and without EV charge loads associated with 150 vehicles as well as the loading of the EV element. It allows a further assessment of the dynamic impact of introducing widespread EV charging dependency upon the substation. It is clear, as made by the previous assessment, that the EV charging load is added to the already existing substation loading at the time which is least suitable, which is during peak hours throughout the middle of the day.

It is unfortunate that the peak EV requirements occur at the same hours as the pre-existing substation demand. However, the chart shows that significant peak reductions can be made by re-distributing the EV and existing power demands so as to level out the demand profile and also minimise the maximum power demand.

4.3 Set 3 Widespread EV in a Gone Green Scenario

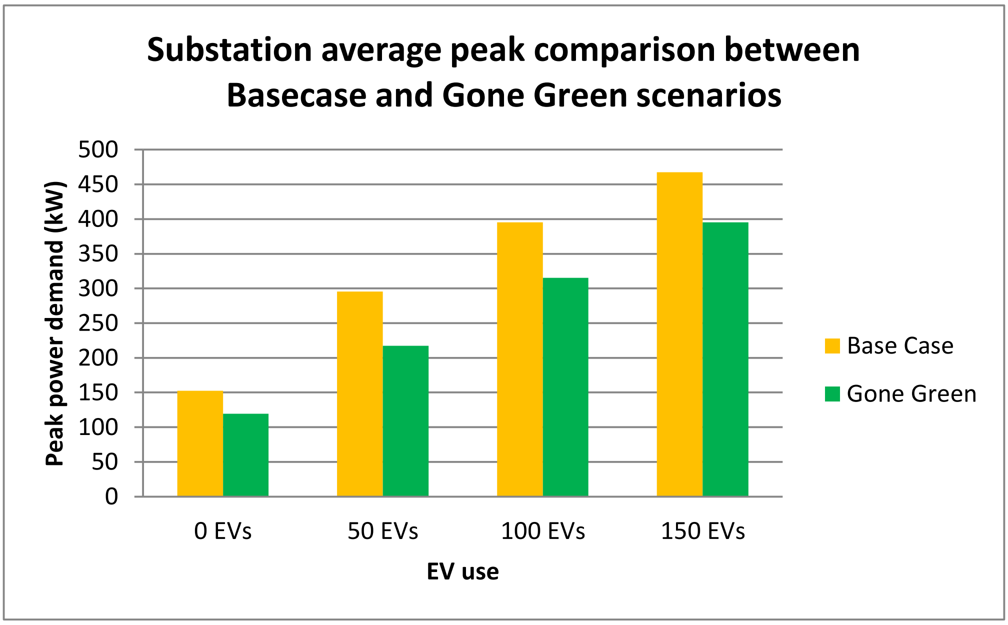

Figure 30 Comparison of Base Case and Gone Green scenarios on introduction of widespread EV use

The comparison of substation peak power loading between base case and Gone Green scenarios for a range of EV usage can be assessed in Figure 30 above.

The reduced peak demand of a gone green scenario is clear to see in the 0 EVs bars. The peak is reduced by approximately 20% to 120 kW. With 150 EVs, peak demand increases to approximately 390 kW which is approximately 15% less than the base case scenario with 150 EVs. This therefore demonstrates, that adopting energy efficient strategies can help mitigate against widespread EV use.

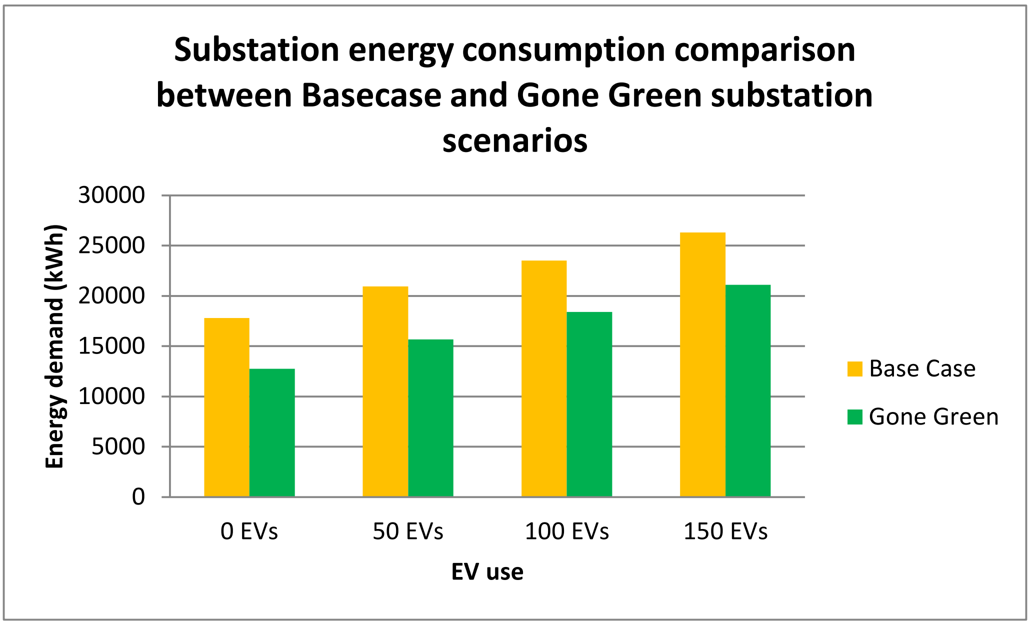

Figure 31 Comparison of Base Case and Gone Green scenarios on introduction of widespread EV use

The difference between the impacts the two scenarios has on the energy demand for widespread EV use is again clear to assess from Figure 31. The graph compares the impact of different levels of EV use on a base case demand scenario alongside the 'gone green' scenario.

Introducing more EVs has caused significant increase to energy demand from both bases case and 'gone green'. The benefit of the gone green scenario is that it results in a reduction of approximately 20% in energy demand from the base case scenario with 150 EVs reliant on the substation for charging.

The details of the 'gone green' scenario are provided in section 3.2.3.

4.4 Set 4 Mitigation Measures Sensitivity Analysis

This section of the results assessment analysis the substation peak demand and weekly energy demand sensitivity analysis of adjusting the demand settings, such as improving building efficiencies, incorporating EHP, PV EV charging rates etc. A full investigation matrix with values of all adjustments made to the scenario settings is provided within the appendix of this report (see section 6.1.4).

The purpose of the sensitivities study is to determine the optimal value of the scenario settings in order to minimise energy demand and peak demand loading on the substation, as explained in detail within section 3.2.4 of this report. The optimal settings will also be assessed for their feasibility and considered for the final mitigation strategies.

The peak demand assessed is the average peak over the seven days of the week. This has been done in order to provide a fair assessment of the peak demand, because the daily peak over the seven days does not reach the exact same value.

It should be also noted that all runs presented in section 4.4 as part of the sensitivity assessment where carried out for a winter week and for 150 EVs to be reliant on the substation with a diversity factor of 0.5 applied throughout.

4.4.1 Electrification of Heating and EHP

Electrification of heating systems will have the adverse effect of increasing the loading on the substation. However, this applies to resistance heaters that have a COP of 1. If an Electric Heat Pump (EHP) system is introduced with an improved COP of 3, then this would reduce power consumption. Figure 32 below shows the outcome of this electric heating sensitivity analysis.

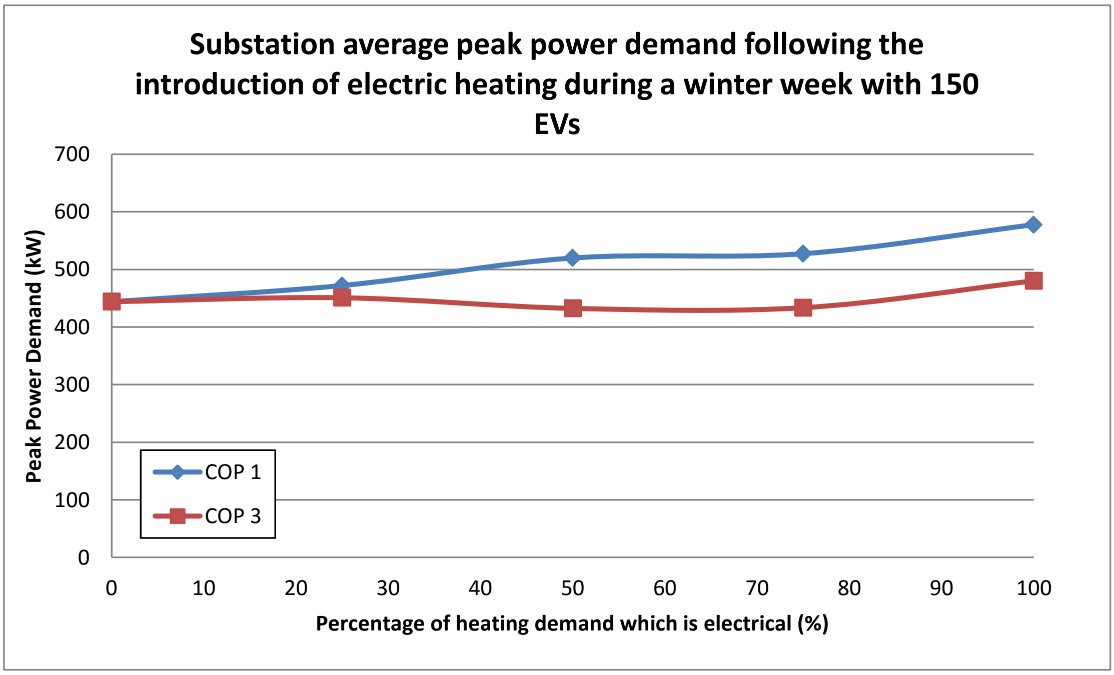

Figure 32 Substation peak power with the introduction of electric heating (COP 1 & 3) and 150 EVs during a winter week

The chart shows with the conventional electrical heating systems (COP 1) the peak power demand increases as the percentage of heating supplied by electrical systems also increases, as to be expected. So, there is clearly no benefit here to help decrease peak loading.

However, if the electric system is a EHP with a COP of 3, there is a reduction in peak power demand between 0% and 75% (levels of EHP integration), from approximately 450 kW to 430 kW respectively, this equates to almost a 4.4% reduction in peak power in comparison to using 0% electric heating. So, 75% electrical heating with COP 3 will be considered as the optimum heating setting for a mitigation strategy to help minimise peak power demand.

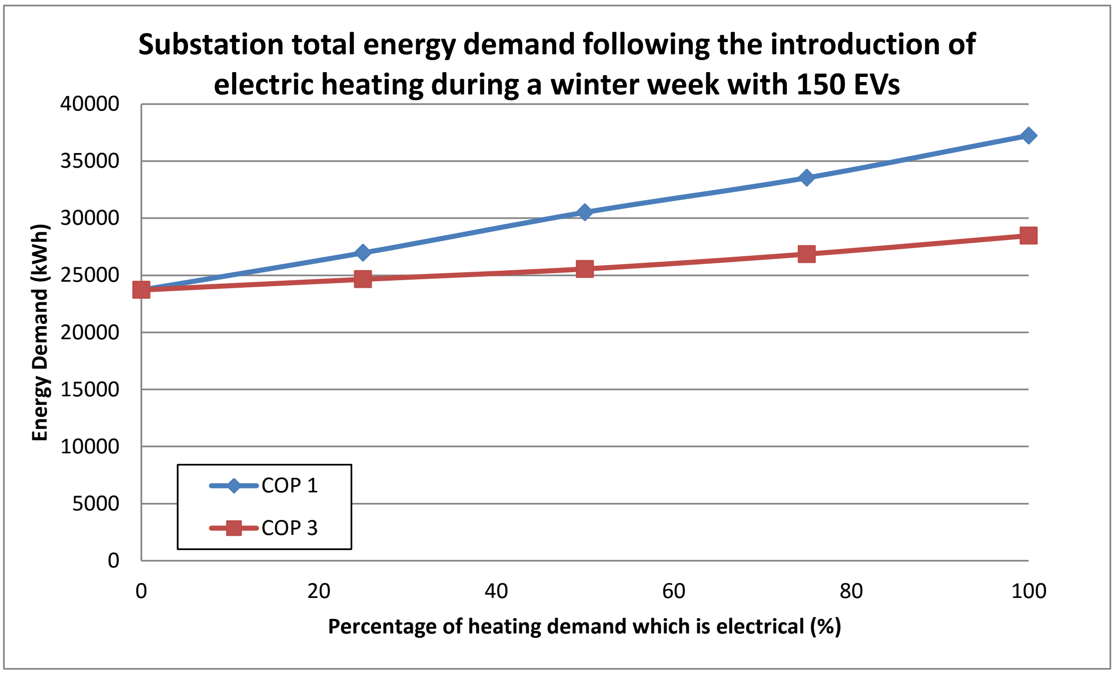

Figure 33 Substation energy demand with the introduction of electric heating (COP 1 & 3) and 150 EVs during a winter week

Figure 33 shows how the weekly energy consumption of the substation increases as the electrical heating increases. As expected this is true for both COP1 and COP 3 electrical heating systems, although there is less of an increase with COP 3, and COP3 has the added benefit of reducing the peak power demand as discussed previously.

The energy demand of incorporating EHP (COP 3) heating system increases the electrical energy consumption from approximately 23.7MW to 28.5MW between 0% and 100% integration. This equates to an increase of 21% which is considered significant. However, as assessed from Figure 32, improvements can be gained from reducing the peak power demand.

The investigation has not considered thermal energy saving from the transfer between conventional heating systems to electrical heating systems, as this investigation only considers electrical loading.

4.4.2 Increasing efficient electric lighting use

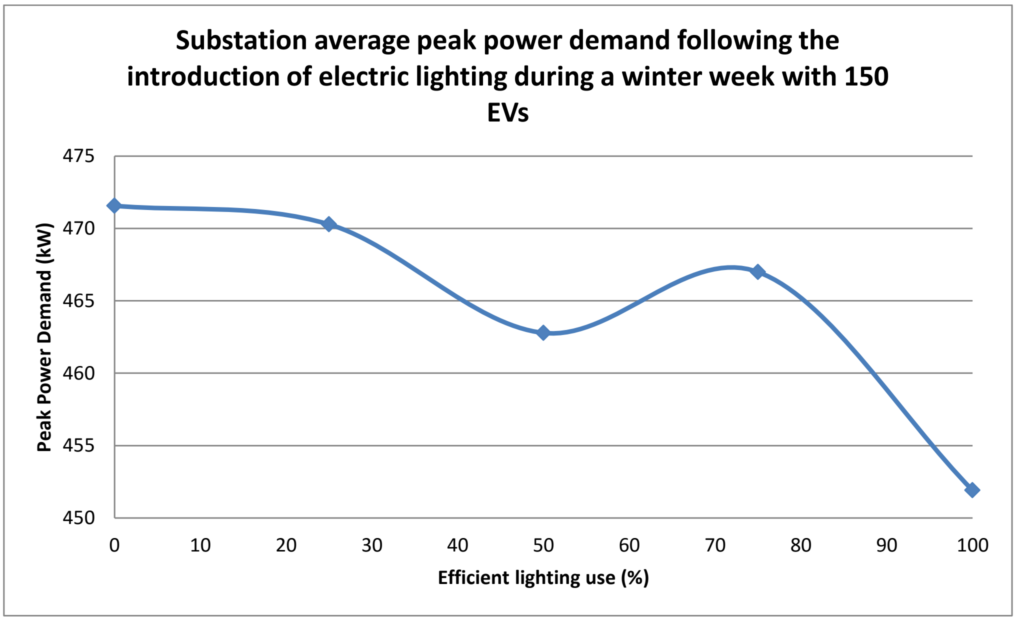

Figure 34 Substation peak power with the introduction of efficient electric lighting and 150 EVs during a winter week

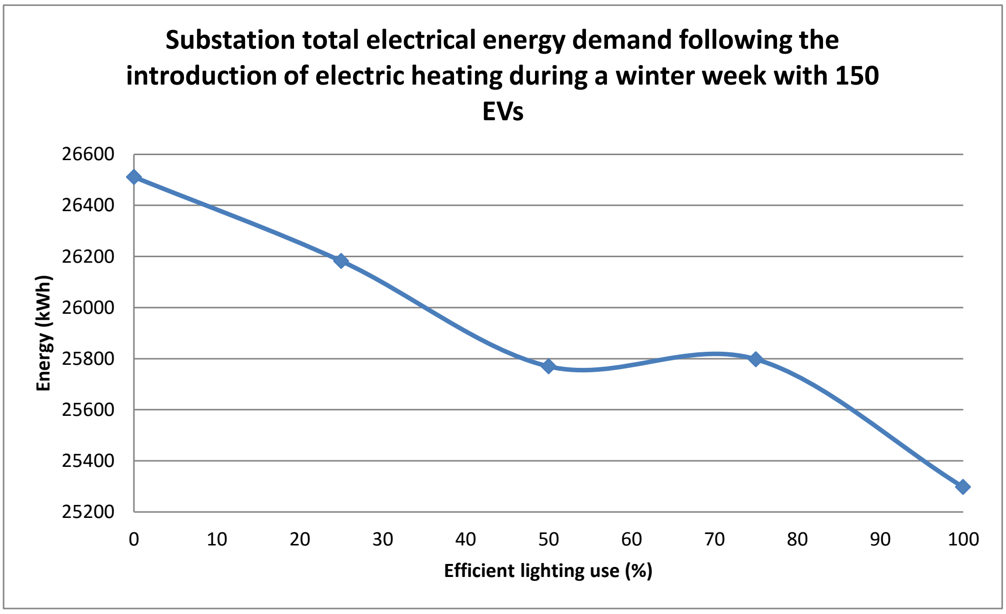

Figure 35 Substation energy demand with the introduction of efficient electric lighting and 150 EVs during a winter week

Figure 34 above shows the influence introducing more efficient lighting systems has on the substation peak power demands. The lowest peak is at approximately 452kW with 100% efficient lighting which is approximately 20 kW less than when using no efficient lighting. This equates to a 5% reduction.

The assessment of Figure 35 above shows the reduction in weekly electrical energy consumption, and as expected, the consumption decreases as the amount of efficient lighting increases. There is a 5% reduction in electricity consumption following 100% use of efficient lighting.

Achieving a 100% implementation of efficient lighting systems is considered feasible and will be carried over to be included as part of the mitigation measures.

4.4.3 Changing EV charging power

This part of the sensitivity analysis is aimed at determining the impact the charging power has on the substation peak power and energy demand. A range of charging power was selected based upon standard installations in Glasgow as discussed earlier within this document (see section 2.2.4). Glasgow city council favours the 22kW charging points for widespread implementation. Other charging powers are publically available in Glasgow such as 7kW and 50kW as well as a role out of Tesla 120kW fast charging stations. This section will assess which of these charging powers has the minimal impact on peak power and weekly energy demand with 150 EVs.

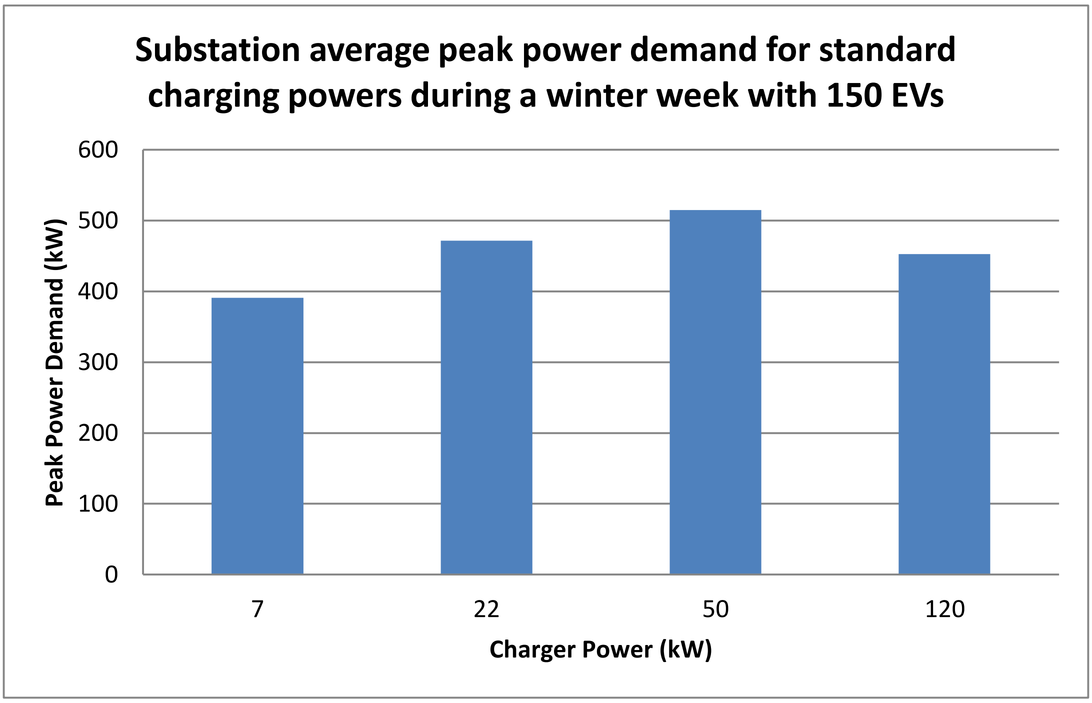

Figure 36 Substation peak power at different charging powers and 150 EVs during a winter week

Figure 36 above presents the weekly average peak demand for 7kW, 22kW, 50kW and Tesla's fast charging power standard of 120kW. Using only the 7kW charge loading upon the substation resulted in the lowest peak power demand of 391kW. The Peak demand using GCC chosen standard of 22 kW increases the average peak demand by approximately 20% as the average peak demand is 471 kW. Using 50 kW chargers had the greatest impact on the substation peak demand with the peak averaging at 515 kW during the sample week. Up to this point there is an apparent positive correlation between the average peak and the power output of the charging points being fed by the substation. And the fact that peak increases with higher rated charging points is to be expected.

However, the chart also demonstrates if the charging power of the charging points significantly increases to 120 kW, the average peak demand actual decreases to 450 kW, which is lower than the 22 kW level. The reason for this occurrence is considered to be due to the faster the charging rate means there is a shorter charging duration for each of the 150 EVs that need charging during the day. Because of this, the stack of EVs charging at any one time decreases, therefore, reducing the peak charging demand. This is a phenomenon that was not predicted and could be the subject of further investigation.

The percentage difference between the GCC favoured 22 kW rated charging and Tesla’s preferred 120 kW on the substation demand is only 4%, and presence a new perspective of the benefit of Tesla’s favoured approach to vehicle charging.

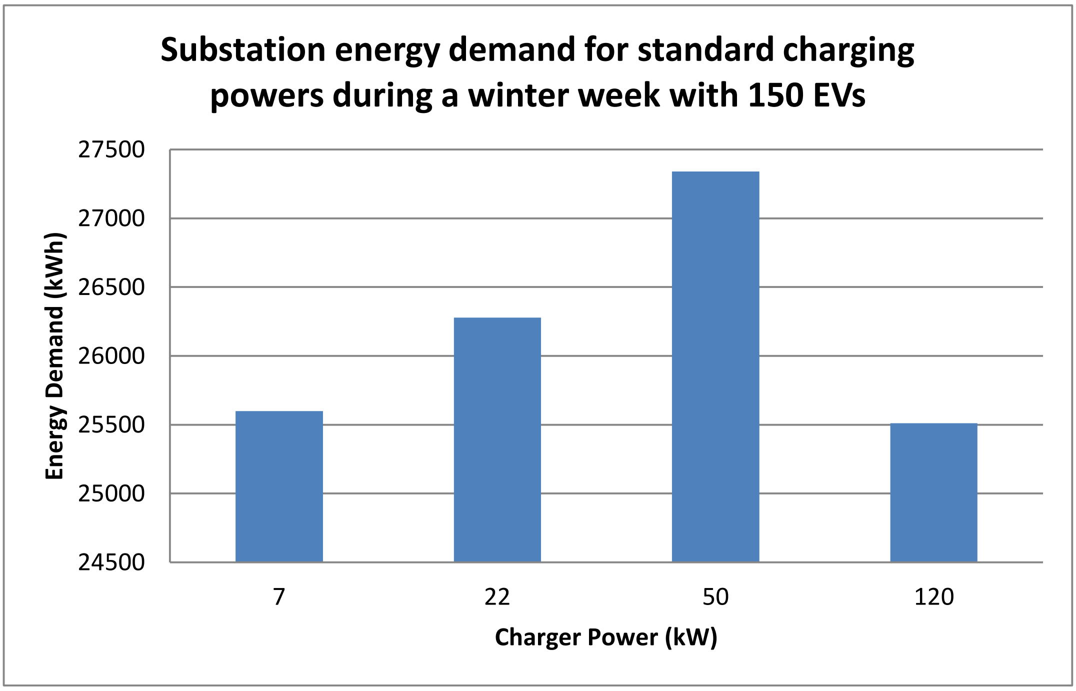

Figure 37 Substation energy demand at different charging powers with 150 EVs during a winter week

The winter weekly energy demand for the range of charging powers are presented within Figure 37 above. As with the average peak assessment previously discussed, it is clear that the substation energy demand increases if the standard charging power of the charge points is increased, but for only 7 kW through to 50 kW. The 7 kW charging power resulted in an energy demand of 25.6MW, when the charging points are rated at 22 kW the weekly energy demand is 26.3MW which is a difference of 2.7%. The 50 kW charging standard has a significant impact on the weekly energy demand as the demand is at 27.3MW which is approximately 6.6% greater than the energy demand with 7 kW charging points. Again, the increase in weekly energy demand is expected following the introductions of higher rated charging points.

However, the unexpected outcome is the significant reduction in energy demand following the introduction of Tesla’s favoured 120 kW charging stations being used in the scenario.

The weekly energy demand using this variant of charging station is 25.5MW which is marginally lower than the demand associated with the lowest power charging station of 7 kW.

4.4.4 Increasing PV installation

The PV trial assesses the impact of increasing the PV installation on the substation peak power and weekly energy demand during a winter week. The amount of installed PV is physically restricted by the availability of clear roof space in which it is possible to install PV panels, also buildings are typically multi-storey and have a high building density meaning it is difficult to install a high percentage of PV (as a percentage of total floor area for which the substation is supporting). In this sensitivity study, PV installation has been limited to only 15% of total floor area (which is still considered too optimistic).

PV is categorised as a generator. Up to now, only consumption has been adjusted by installing more efficient systems and change how generated power is used. Instead, PVs supplement substation supply therefore reducing the substation demand.

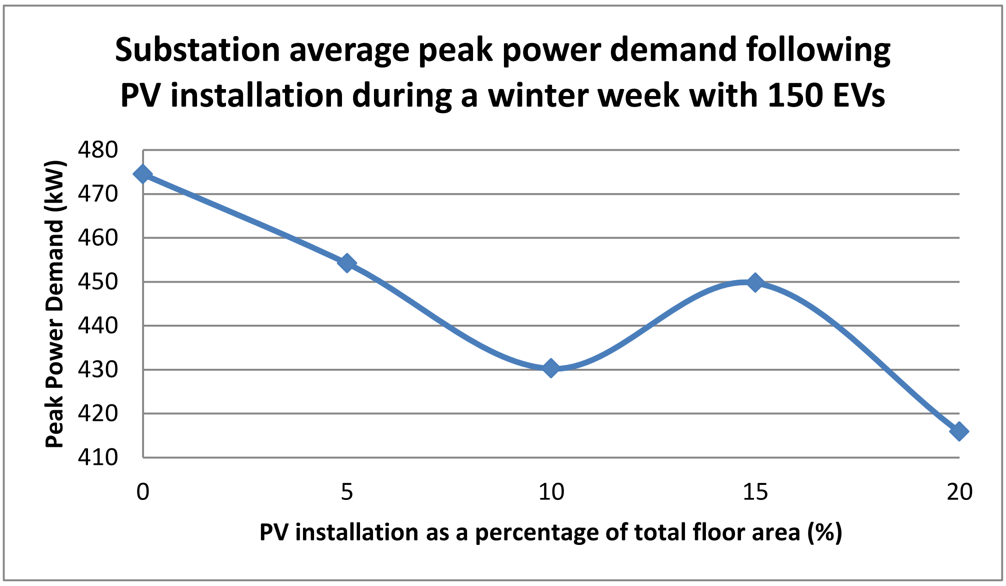

Figure 38 Substation peak power with the introduction of PV installations and 150 EVs during a winter week

Figure 38 above shows a significant reduction in peak power demand with 15% PV installation. In this scenario, peak power is at 415kW, which is a 13% reduction in peak demand compared with no PV installed.

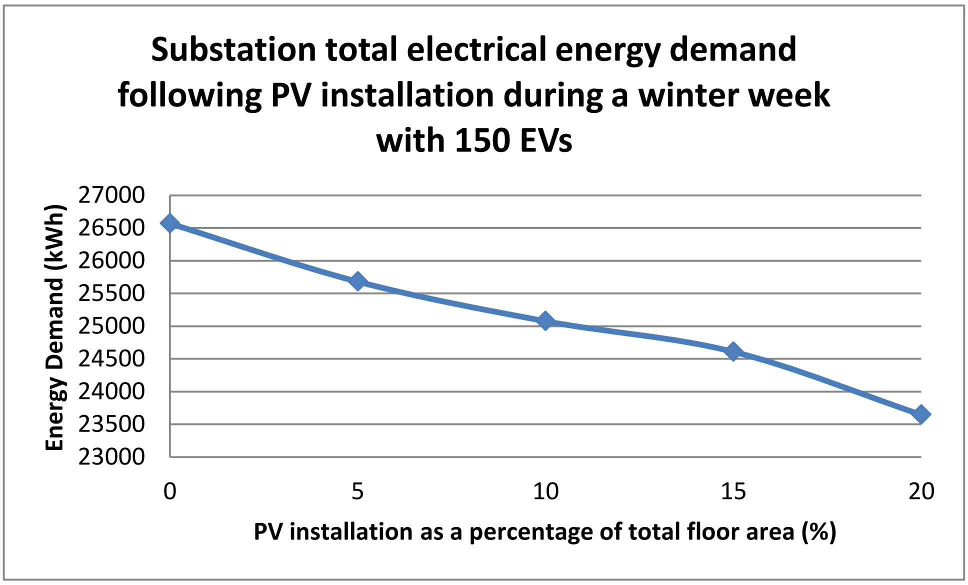

Figure 39 Substation energy demand with the introduction of PV installations and 150 EVs during a winter week

15% PV installation also results in significant reduction in energy consumption, as shown in Figure 39. The improvement in energy consumption is 10% down to approximately 24.6MWh for the week.

It is considered that 10% – 15% of PV installation as feasible in the best possible circumstances, this conclusion will be carried over to compiling final mitigation strategies.

4.4.5 Adjusting CHP

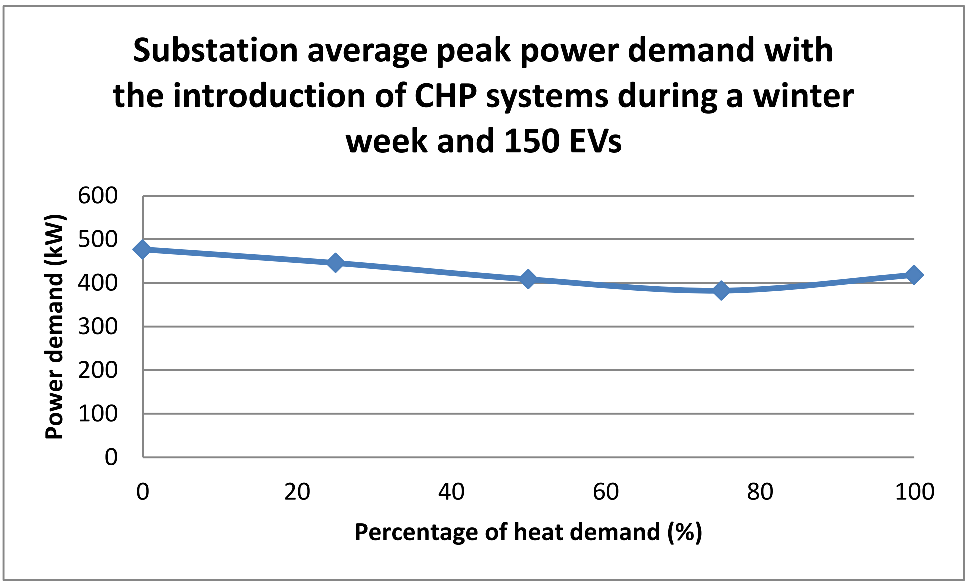

Figure 40 Substation peak power with the introduction of CHP and 150 EVs during a winter week

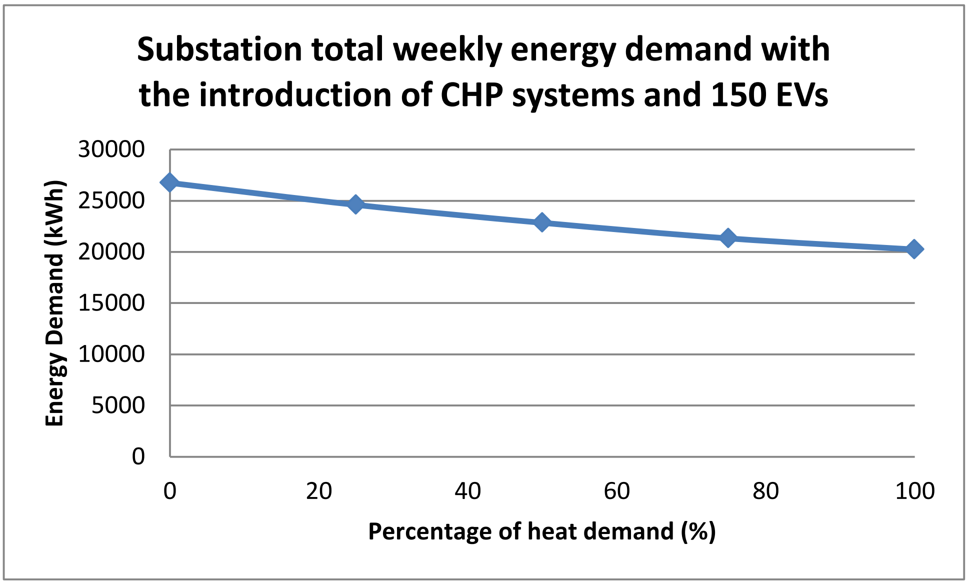

Figure 41 Substation energy demand with the introduction of CHP and 150 EVs during a winter week

The impact of introducing combined heat and power (CHP) units reduces the substation peak demand and this is shown in Figure 40. When 75% of heating is provided by CHP the peak power is lowest the peak power reduces from 475kW to 380kW which is approximately 20%. However, 100% CHP integration results in a peak power demand increase up to 420 kW. This demonstrates that 75% is the optimum CHP integration for this scenario.

Figure 41 shows the effect of increasing the amount of CHP supplying heat has on reducing the substation electrical energy demand. As expected, it is clear as the use of CHP reduces substation energy demand from the grid as CHP. With no CHP, the electrical energy for one week is 26.8MWh and gradually linearly decreases to 20.2MWh with 100% CHP integration. This is a 25% reduction in electrical energy demand and is considered to be a substantial. From this it is clear that utilising a high level of CHP should be part of the final mitigation strategies.

4.4.6 Changing CHP Heating to Power Ratio

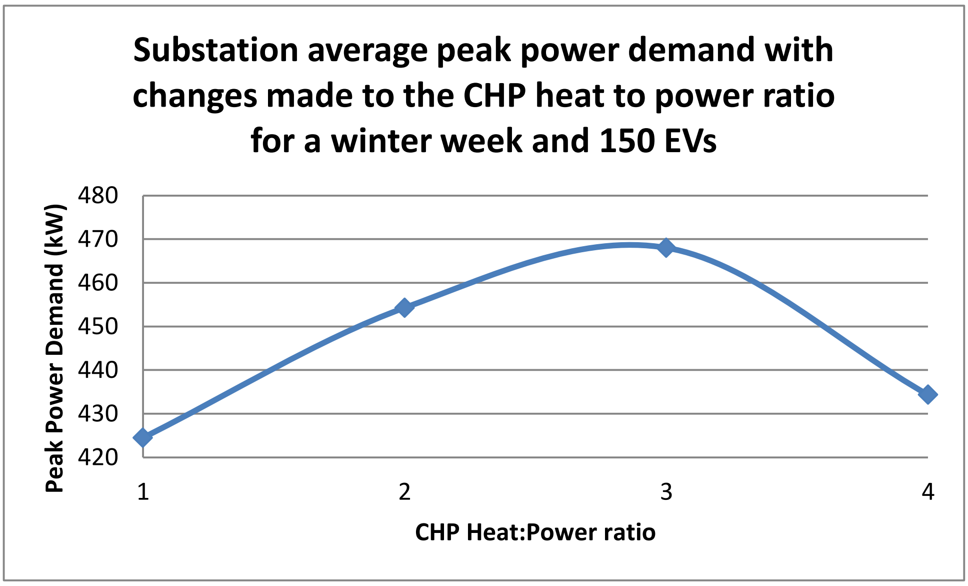

Figure 42 Substation average peak power with adjustments made to the CHP heat to power ratio and 150 EVs during a winter week

The chart shown in Figure 42 above presents the results of the sensitivity assessment of changing the heat to power ratio of the CHP heating system on the substation peak loading (CHP heating penetration is set to 25%, see investigation matrix in appendix section 6.1.4). It is clear from the chart that when the ratio is 1, the peak power is at the lowest value of approximately 424 kW. As the heat to power ratio increases, the average peak power also increases to 468 kW when the ratio is set at 3. This equates to a difference of 10%. However, when the ratio was increased to 4, the average peak power demand dropped back down to 434 kW.

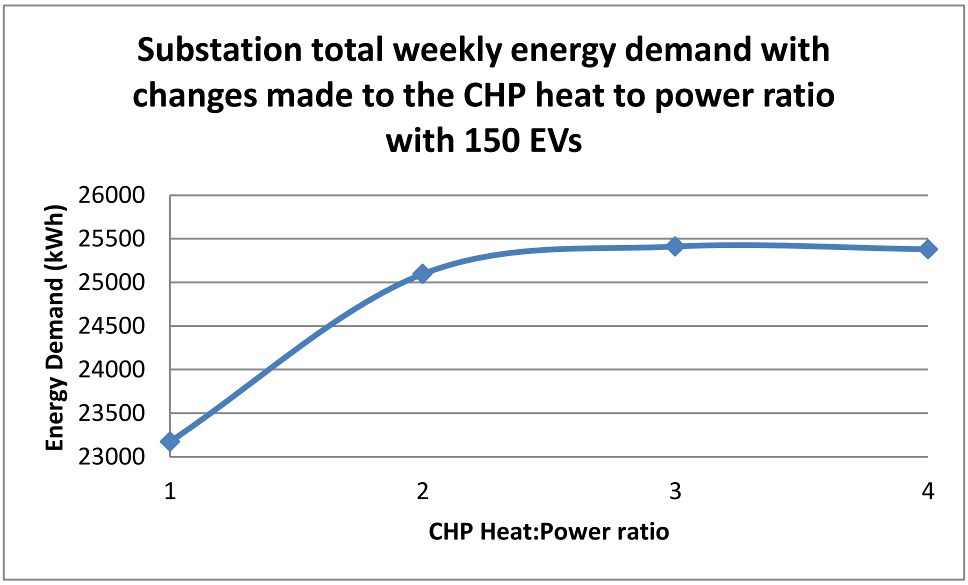

Figure 43 Substation weekly energy demand with adjustments made to the CHP heat to power ratio and 150 EVs during a winter

Figure 43 above shows the substation weekly electrical energy demand for CHP heat to power ratio changes of 1 through to 4. As expected, the lowest electrical energy load is when the ratio is at 1. Here the weekly energy demand is approximately 23MW. When the ratio is set to 2, the weekly electrical energy demand significantly increases to 25MW which equates to approximately 8% increase in demand. Subsequent heat and power ratios (3 and 4) have similar impact on the substation energy consumption in comparison with the ratio of 2.

As the heat to power ratio increases, heat energy contribution stays the same (25% in this case), but the magnitude of electrical energy decreases. Therefore, we find the electrical power contribution of the CHP reduces, and will increase the load on the substation, as is consistent with the results presented on Figure 42 and Figure 43 above.

The minimum peak power and weekly electrical energy consumption from having the heat to power ratio set to 1 would suggest that this is the optimal setting to carry over for the mitigation strategies.

However, consideration must be given towards realistic and feasible CHP installations and actual ratios that are available and achievable. Following a review of CHP and existing systems (see section 2.6.2.1 of the literature review), a best case CHP heat to power ratio of as low as 1:1 is realistic for widespread implementation. Therefore, a ratio of 1:1 will be carried over for the mitigation strategies.

4.4.7 Adjusting EHP to CHP balance

As detailed within the literature review section of this report (refer to section 2.6.3.2), a previous study (Mancarella, et al., 2011) had assessed the impact changing the EHP to CHP heating supply ratio on electrical power and energy demand. The study demonstrated there is a possibility of reducing electrical power and energy savings to be made by changing the balance of EHP to CHP. This section of the sensitivity study aims the replicate the conclusions made by Mancarella, that by having an EHP to CHP heating balance of 20%:80% helps reduce the electrical power and energy loads.

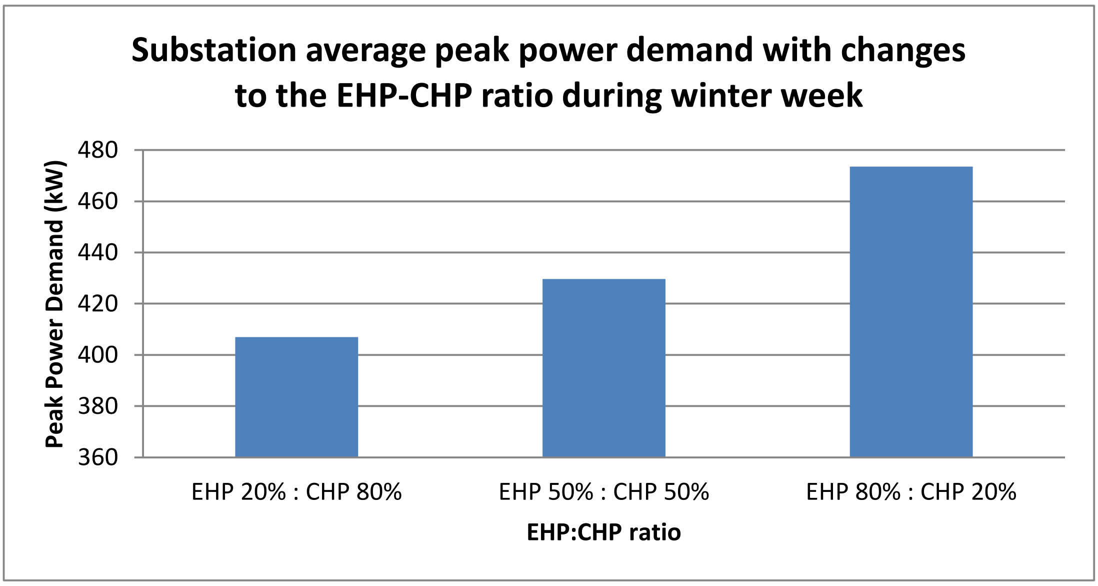

Figure 44 Substation average peak power with adjustments made to the EHP to CHP ratio and 150 EVs during a winter week

Figure 44 presents the three EHP to CHP balances investigated for a winter week with 150 EVs reliant on the substation, and the impact on the average weekly peak power demand. The 20:80 had the lowest average peak demand of 406 kW. When the balance was adjusted to 50:50 the average peak demand increased by approximately 5% to 430 kW. The 80:20 combination had an average peak demand of 474 kW which is 16% greater than the 20:80 combination.

The reason for the improvements to peak power is considered to be due the greater the levels of CHP integration the greater electrical power is delivered by the CHP which therefore reduces demand required from the substation. Electrical heating efficiency is increased by the utilisation of a EHP system with a COP of 3. It should be noted the EHP systems have a COP of 3 throughout this sensitivity.

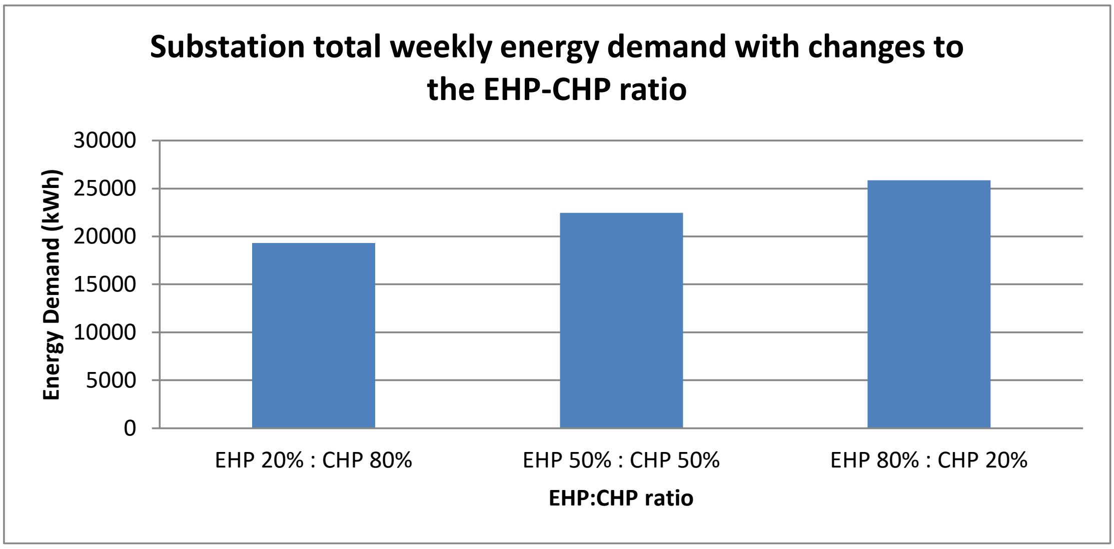

Figure 45 Substation weekly energy demand with adjustments made to the EHP to CHP and 150 EVs during a winter

Figure 45 shows the substation weekly electrical energy consumption for the different EHP and CHP combination balances. Again, the greatest reduction is achieved by the 20:80 combination where the substation energy consumption was 19.3MW. When the EHP and CHP are evenly balanced (50%:50%) the weekly substation energy consumption is 22.5MW which is 16% greater than 20:80. When the balance was adjusted to 80:20, the substation weekly energy consumption was 25.9MW, which is 34% greater than the 20:80 EHP to CHP combination.

From this assessment it is clear that there are significant improvements to the substation peak power loadings and energy consumption, and the 20:80 EHP and CHP combination should be carried over for consideration to be used in the mitigation strategies because it demonstrated the lowest substation peak demand and weekly energy consumption and considered to be feasible with widespread implementation.

4.4.8 Heating load shifting

The DPG tool allows for adjustments to shifting a portion of heating loads in order to reduce peak loading caused by heating. It also allows a heating penalty to be applied to the load shifting which determines the amount of heat energy lost through system losses and inefficiencies. The investigation matrix for this sensitivity study is presented in section 3.2.4.

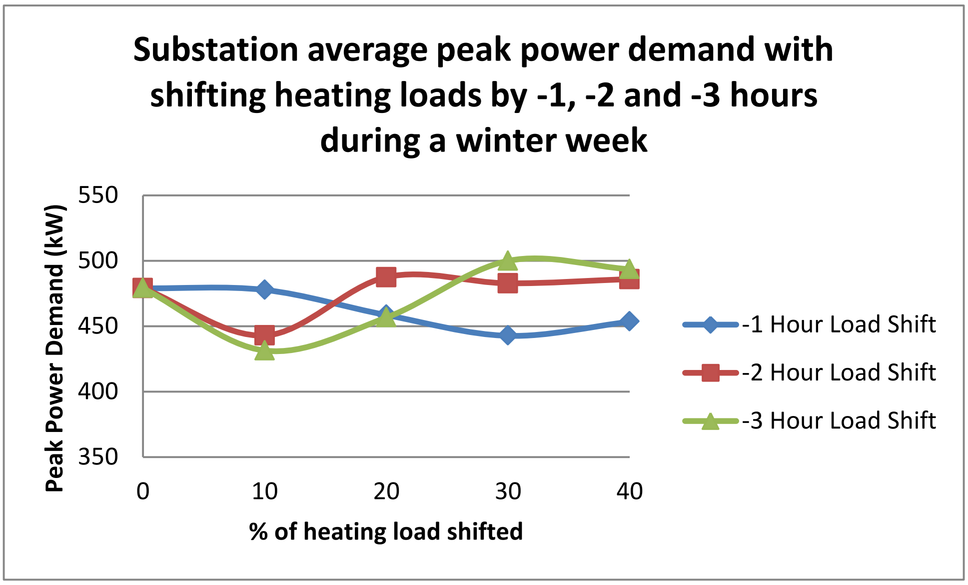

Figure 46 Substation average peak power demand with shifting a proportion of heating loads to -1, -2 and -3 hours. During a winter week and 150 EVs

Figure 46 presents the substation average peak power demand following the changes made to the load shifting for a range of portion of heating power and a shift of 1, 2 and 3 hours. It should be noted that the negative sign implies time shift prior to the original median. The range of percentage of heating load shifted investigated was between 0 and 40%.

It is clear from Figure 46 that changing the heating load shift will change the peak power demand. Changing the amount of time to which the portion of heating is shifted again has an impact in the peak power demand. It is difficult to determine a clear trend, but if the worst case and best case are compared, then the magnitude of the potential peak reduction that can be achieved is determined.

When there is no load shift applied the average peak demand is 479kW. The largest peak reduction is achieved by introducing a 10% heating load shift and -3 hour time shift. This reduced the peak load down to 431kW. This equates to a significant reduction of approximately 10%. The other significant reduction can be achieved by introducing a 30% heating load shift and time shift by -1 hour. This combination reduces the peak power down to 443kW, which is a reduction of 7.5%. 7.5% reduction in substation peak power was also achieved by 10% heating load shifted by -2 hours.

The reason for the changes to the peak could be put to the simple redistribution of the electrical heating demand but a further understanding of the benefits of applying the heating load shift may be given by assessing the impact on the substation energy consumption as discussed below.

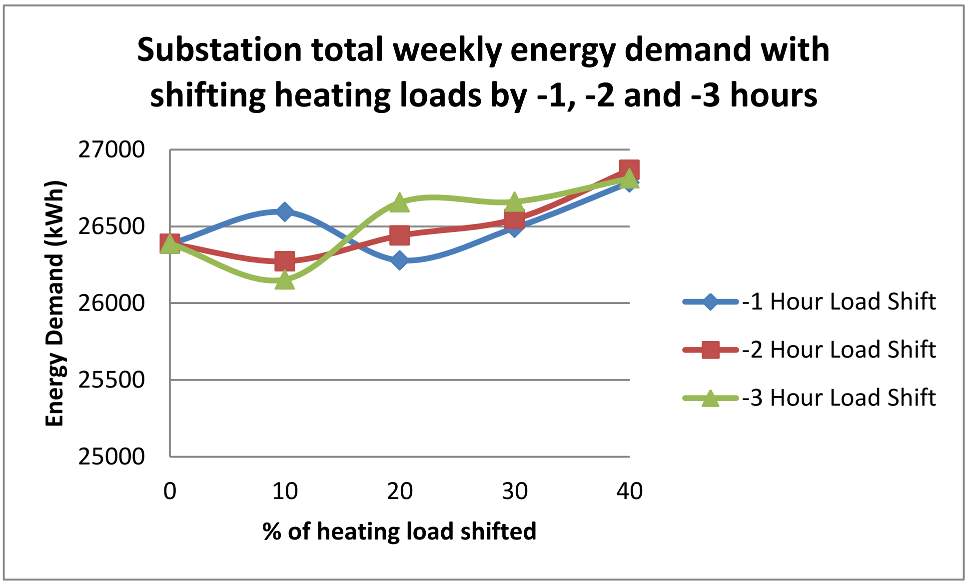

Figure 47 Substation weekly energy demand with shifting a proportion of heating loads to -1, -2 and -3 hours. During a winter week and 150 EVs

The substation weekly energy demands for different heating load shift settings are shown in Figure 47 above. Again, due to the spread of results it is difficult to determine any real correlation, apart from the scenarios where the percentage of heat load shifted is 20% or greater. Here the energy demand increases, and applies to -1, -2 and -3 hour time shifts.

For all three cases, when 40% of heat load is shifted, they all are at their maximum weekly energy consumption (within the scope of the assessment) of approximately 26.8MWh. This is a 3% increase in weekly energy consumption from the scenario with no heating load shifted.

Three heat load shifting scenarios did show a reduction in weekly energy consumption. Firstly, 20% with -1 hour time shift reduced the consumption down to 26.3MWh; 10% with -2 hour time shift reduced consumption to 26.3MWh and 10% with -3 hour time shift which had the greatest improvement with a demand of 26.2MWh. The percentage reduction equates to 0.4%, 0.4% and 0.8% respectively.

Although, with respect to the magnitude of substation electrical energy savings that can be made, the possible savings are small and not hugely significant but is still a marginal gain, and seen as easily implemented due to the relatively small percentage of heating loads to which the heat shift can be applied to.

Clearly, with respect to minimising the energy loading, the portion of heat load shifted should be kept to between 10% and 20%.

It is clear that significant peak power and energy consumption improvements can be made, but in order to select suitable settings for consideration in the mitigation strategy, consideration must be giving to the feasibility of the settings. Such as, is it easier to apply a small time shift to a small portion of the heating load or to apply a large time shift to small portion of the heating load? For this situation it is considered that the former is perhaps most appropriate for real world implementation.

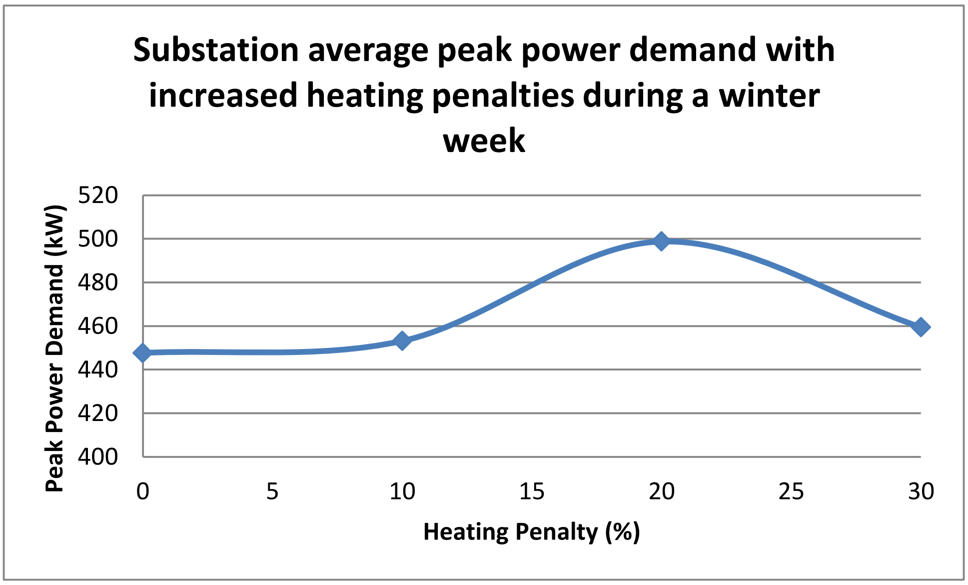

Figure 48 Substation average peak power demand with increasing heating penalties with 40% portion of heating shifted by -3 hours during a winter week and 150 EVs

The impact of changing the heating penalties was applied to a case of 40% heat load shifted by -3 hours and the results are presented in Figure 48 and Figure 49 showing the changes in average peak power demand and weekly energy demand respectively.

Figure 48 shows that the substation peak power demand appears to stay in a range of approximately 10%, where the largest demand occurred when the penalty was set to 20% and the lowest average peak demand occurred when there was 0% penalty applied. The fact that the lowest occurs with no heat penalty is to be expected, as reducing heating loss will reduce heat demand therefore this will have an impact of reducing the peak demand. However, when the penalty was set to values above 20%, there appeared to be a reduction in the peak demand. To understand this situation it is perhaps worth assessing the weekly energy demand.

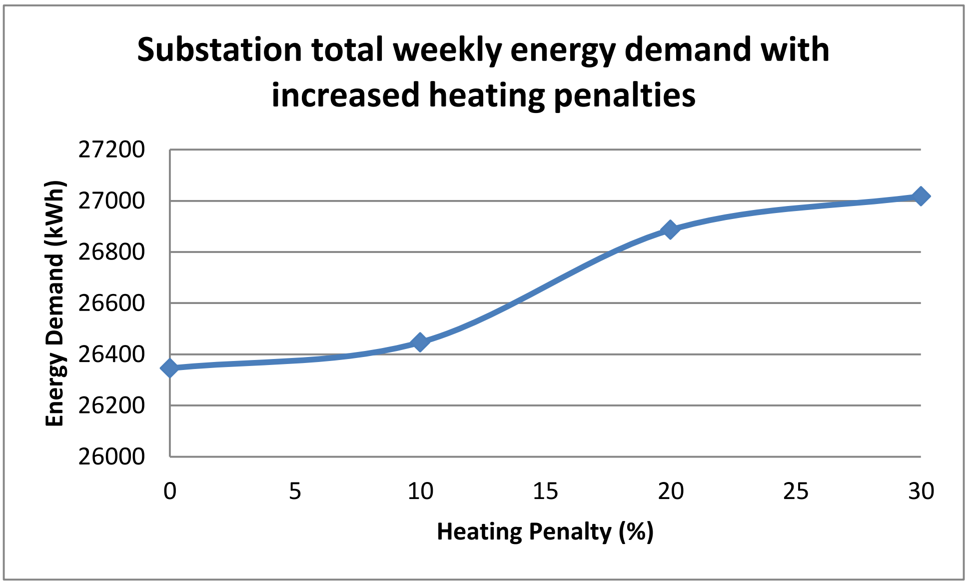

Figure 49 Substation weekly energy demand with increasing heating penalties with 40% portion of heating shifted by -3 hours during a winter week and 150 EVs

Figure 49 above shows an increase in the substation weekly energy demand following an increase in the heat penalty. There appears to be a relatively sharp increase between 10% and 20%. However, what the chart clearly shows, and as expected, in order to minimise energy usage it is necessary to minimise the heat loss penalty.

When the penalty is set to 0%, the weekly consumption is 26.3MWh and when the penalty is set to 30%, the consumption is 27MWh, which is an increase of approximately 2.7%, which is not hugely significant but is still a marginal gain to be taken into consideration for the mitigation strategies.

4.4.9 Reducing small electrical appliance demand

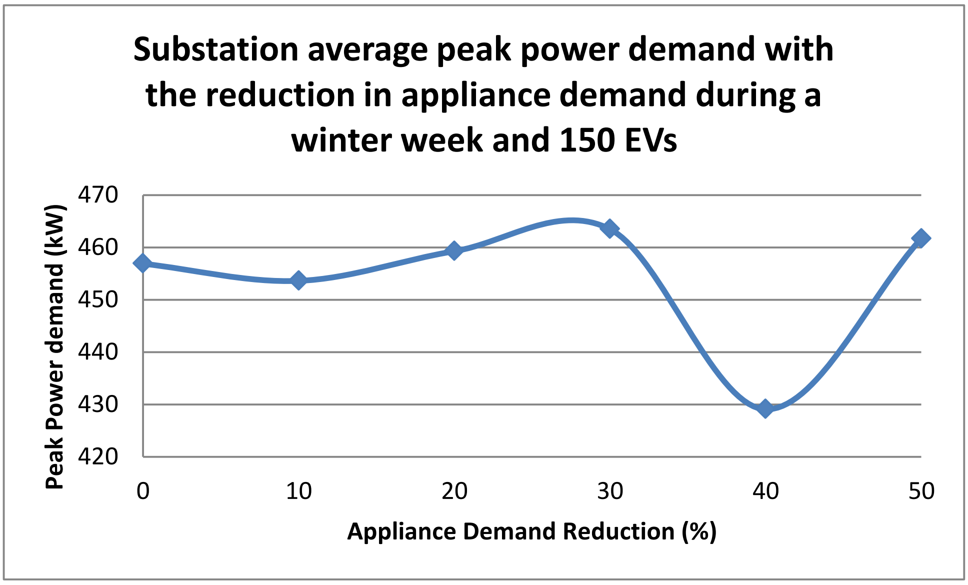

Figure 50 Substation peak power and reducing appliance demand and 150 EVs during a winter week

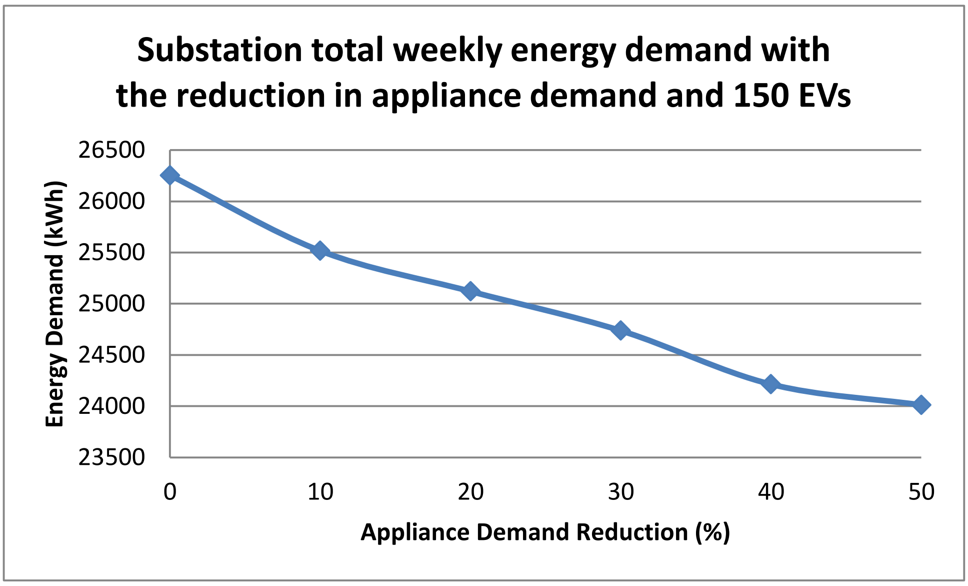

Figure 51 Substation energy demand and reducing appliance demand and 150 EVs during a winter week

According to the results presented in Figure 50 above, there appears to be no recognisable correlation between the percentage reduction in appliance demand and the peak substation power demand. The difference between the maximum peak (30% appliance demand reduction) and the minimum peak (40% appliance reduction) is approximately 33kW which suggests there is the possibility of reducing the peak demand by approximately 8%.

The impact of reducing small electrical appliance demand has the obvious benefit of reducing the substation energy demand, and significant reductions can be made over a week as is clearly shown in Figure 51 above.

When there is no appliance demand reduction the weekly energy demand during the winter is approximately 26.2MWh and when the appliance demand is reduced by 50% (although it is considered to be feasibly difficult to implement) the substation energy demand reduces by 7.6% to 24MWh. The relationship between the substation demand and appliance reduction appears to be almost linear. Appliance reduction beyond 50% was not investigated as it was not considered reasonable to reduce appliance demand by a value greater than 50% due to ever increasing reliance on IT systems and infrastructure in offices, as well as the need for kitchen and washing facilities in bar, restaurants and hotels.

Again, the substantial reduction in energy demand by reducing appliance demand will be applied to the mitigation strategies.

4.4.10 Improving building efficiency

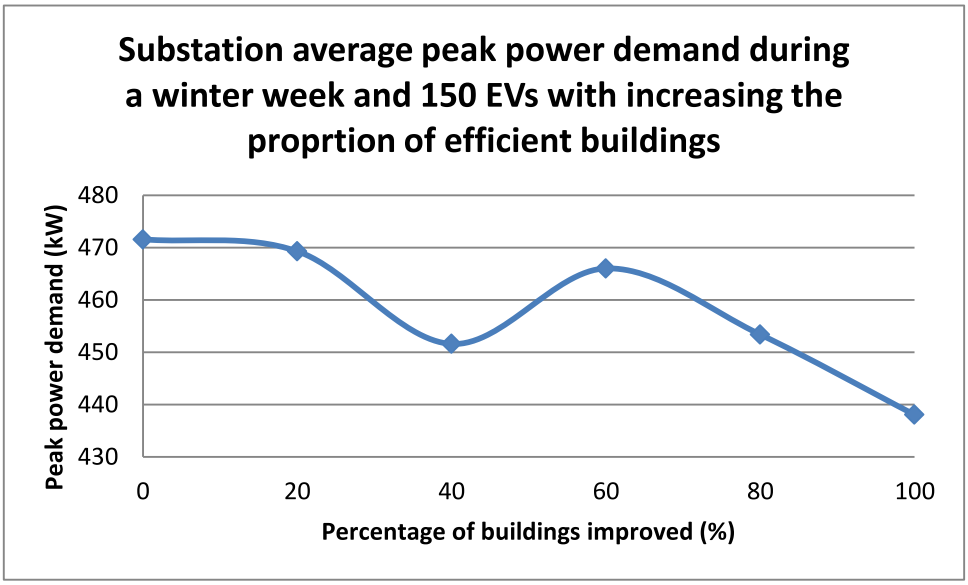

Figure 52 Substation peak power and increasing the proportion of energy efficient buildings and 150 EVs during a winter week

The effect of increasing the portion of efficient buildings being supplied by the substation has on the peak power demand is shown in Figure 52. The chart shows significant peak reductions can be achieved with 100% efficient building integration. The peak at 0% is 472 kW and at 100% is down to 438 kW which is a reduction of 7%. Although, 100% may not be considered feasible, 40% can be, and this reduces peak down to 452 kW which is a 4% reduction, which is significantly greater than 20% or 60% levels of efficient building integration.

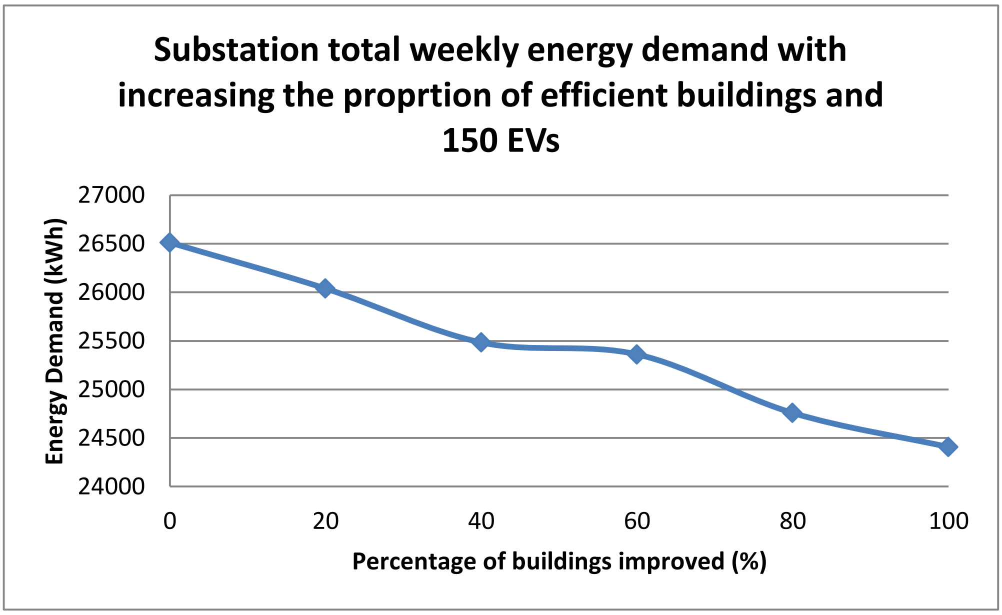

Figure 53 Substation energy demand with increasing the proportion of energy efficient buildings and 150 EVs during a winter week

The potential substation electrical energy savings following increasing the proportion of buildings that are energy efficient is presented within Figure 53 above. It is clear to see the almost linear negative correlation between building efficiency and weekly energy consumption which is to be expected.

With 0% of buildings being of the efficient type, the weekly demand is approximately 26.5MWh. The demand drops by 4% when 40% of the buildings are considered efficient and a drop of 8% when all buildings are considered energy efficient (100%). This lowers the weekly electrical energy demand to 24.4MWh.

This improvement in energy consumption is considered significant however it should be noted that it’s unlikely and not feasible to say it is possible to have 100% of buildings in Glasgow upgraded to passive house efficiency standards, especially as many of the buildings in the city are historical. It is assumed that an integration level of 40 % is perhaps more realistic, despite still being optimistic.

4.5 Set 5 Managing EV Charging Demand Distribution

The impact of changing the charging demand profile throughout the day upon the substation peak power demand and the energy demand is assessed within this section of the document. The charging profile was changed by making adjustments to the DPG visual basic coding to change the charging probability distribution (as explained in section 3.2.5). Results are presented below.

It should be noted that the charging profiles have been applied to the Base Case Scenarios with 150 EVs for a winter week.

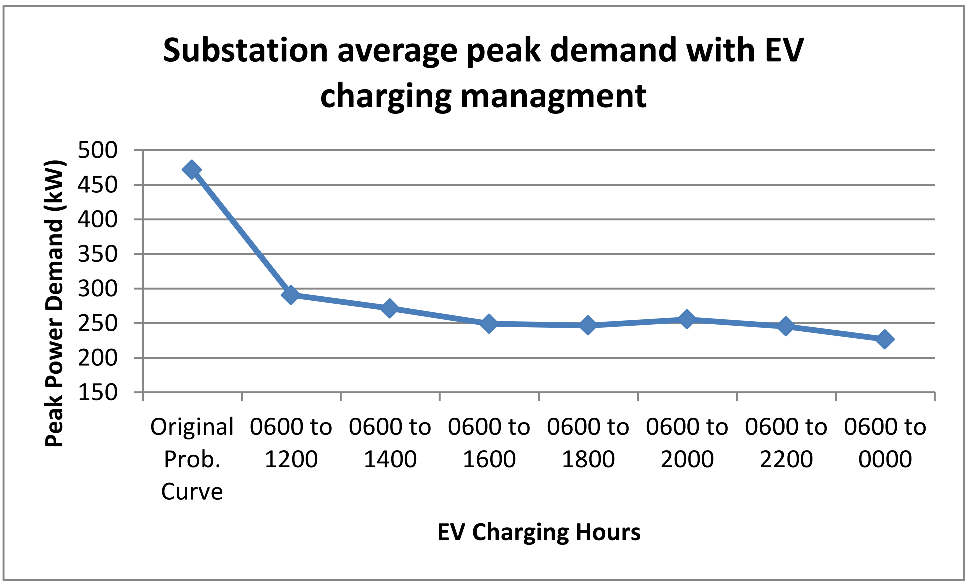

Figure 54 Substation average peak power with EV charging management introduced

It is clear from Figure 54 that there is significant reduction in substation peak power demand following the introduction of charging management. This is to be expected as changing the EV charging profile promotes a more even profile throughout the day reducing chance of high peaking. The difference in peak demand between the original charging profile and the first of the managed charging profiles (0600 to 1200) is approximately 36% which is a substantial improvement.

Furthermore, the trend between the 0600 to 1200 and 0600 to 0000 cases is a gradual decrease down from 290kW to 225kW which is a 20% reduction in peak demand. Therefore, again demonstrates the benefit of managing the EV charging.

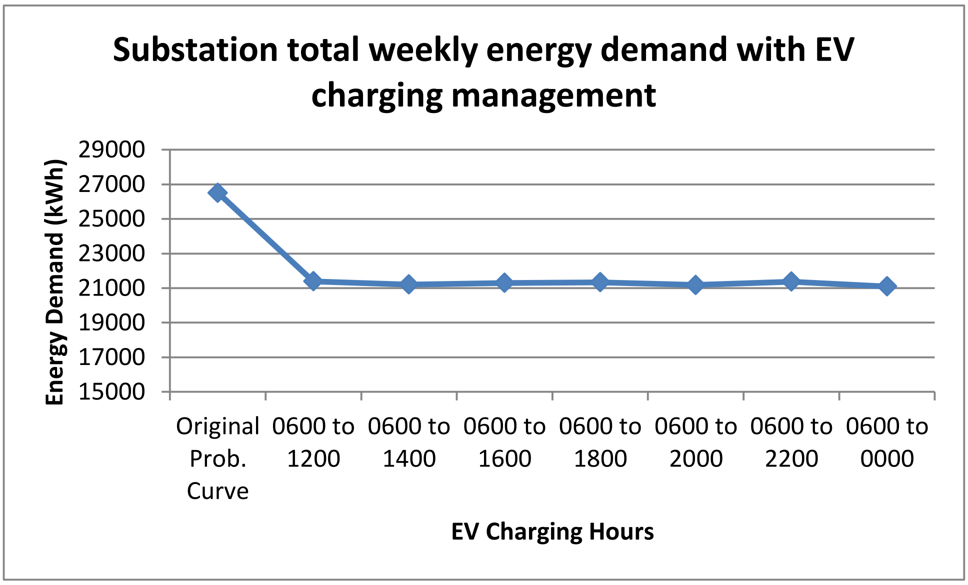

Figure 55 Substation energy demand with EV charging management introduced

Figure 55 above presents the substation weekly demand following the introduction of the charging management schemes. It was expected there would be no difference in weekly energy demand for all scenarios because the accumulated daily requirement for charging is the same. It's just the charging power demand profile that is expected to change (due to the redistribution of the EV charging). The results show this is true for all cases between the 0600 to 1200 and 0600 to 0000.

However, the energy demand of the original charging scheme is approximately 18% greater than all of the seven introduced charging schemes. This is considered to be substantial difference and raises concerns associated with the alteration made to the DPG tool charging function and code. Because of this, this part of the study has been separated from the other sensitivity studies.

Despite the concerns, useful conclusions are still drawn from comparing the peak demand of the seven different charging scenarios introduced.

It is clear that introducing charging management scheme to ensure even distribution of charging, helps improve the peak load. Further improvements can also be made by distributing charging over a greater time span, thus reducing the number of EVs on charge at any single moment again helping to reduce peak loading.

However, the concern from this conclusion is there will be great difficulty in implementing such EV charging management schemes.

The literature section of the report (2.6.1) presented ideas of implementing charging tariffs or TOU schemes to encourage EV users to charge at different times of the day depending on the number of EV undergoing charging time or the already existing load on the substation or grid.

Such charging system could be a manually, automated or a remotely operated systems. Ideas for a remotely operated system is an EV could be plugged into a charger, the EV user could be notified via a phone application when demand is low and charging can then be initiated with the users approval. If the system is fully automated, then the user may define how much charging they require before the end of the working day, and the automated system will decide itself when it is best to commence charging, whilst ensure substation peak limits are not exceeded.

Such concepts for a system would be complex on a city wide scale. However, if controlled on a substation by substation scale, then the system could be easier to implement and automate.

4.6 Set 6 Mitigation Strategy Outcome from the Sensitivity Study

Following the completion of the sensitivity studies as reported in sections 4.4.1 through to 4.4.10, the optimal settings from these investigations were collected together will be applied to the substation loading scenarios.

Table 10 below presents the collection of the optimum settings selected from the sensitivity study and also a second set of settings which are considered the feasible alternative (section 5.2 provides further explanation for the feasible setting). These settings make up the mitigation strategies.

Scenario Variable Name	**Best Setting**	**Best Feasible Setting**	**Explanation for Feasible Setting (also see section 5.2)**
Heat demand supplied by electrical heating (and COP)	20%, COP 3	50%, COP 3	n/a
Lighting control	100%	100%	n/a
EV charging power	7kW	22kW	22kW will be the standard in Glasgow City
PV installations	20%	10%	The level of PV installations in an urban environment will be limited due to available space

CHP	80%	50%	Likely penetration of CHP
CHP heat to power ratio	1:1	1:1	Feasible
EHP:CHP balance	20:80	50:50	Feasible
Heating load shifting	(See section 6.1.6)	(See section 6.1.6)	Based on realistic heating load shift and penalty
Reductions to appliance demand	40%	40%	Considered to be the most the appliance demand can be reduced by
Improvements to building efficiency	100%	40%	Due to the vast range of building age, there is a limit to the improvement of building efficiency.

Table 10 Summary of the best and best feasible settings for reducing substation peak demand and weekly energy consumption which makes up the mitigation strategy

The results from applying the mitigation strategy are presented in Figure 56 and Figure 57 below along with the Base Case and Gone Green scenarios investigated earlier (presented in sections 4.2 and 4.3 respectively).

The charts present the best possible mitigation and what is considered the feasible mitigation strategy for realistic implementation within a matter of decades. Both the ‘realistic’ and ‘best’ mitigation strategies significantly improves the substation peak power loading and the substation weekly energy demand in comparison with the Base Case substation scenario and the Gone Green scenario. It should be noted that each scenario has 150 EVs reliant upon the substation during a winter week.

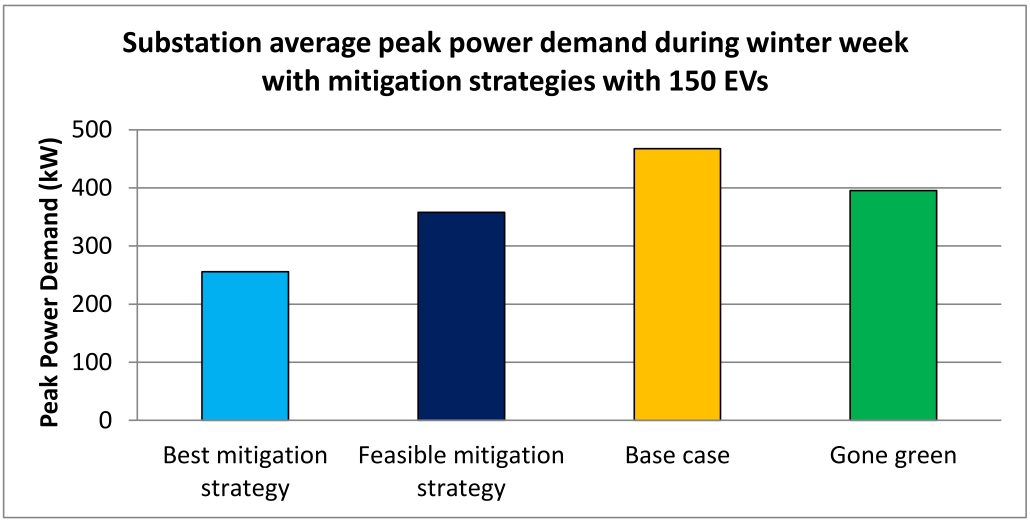

Figure 56 Substation peak power and implementing mitigation strategies and 150 EVs during a winter week

Figure 56 above shows the improvement made to the substation average peak power following the implementation of the mitigation strategies (both best and feasible) over the Base Case and also the Gone Green scenarios.

The 'Best Mitigation' produced an average peak power loading of 256kW, whereby earlier in the investigation it was found that the Base Case had an average peak power loading of 467kW, this equates to a reduction of 45%. The 'feasible' mitigation strategy reduced average peak loading by 23.6 % to 358kW, which is still considered to be a substantial improvement on the Base Case and shows that significant reductions in the substation peak demand can be made with a feasible mitigation strategy.

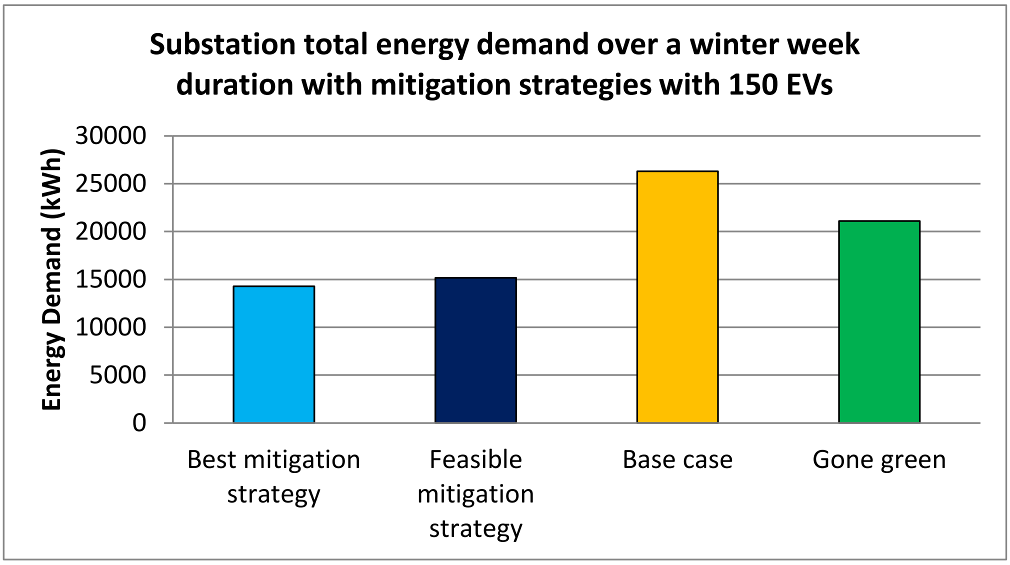

Figure 57 Substation energy demand and implementing mitigation strategies with 150 EVs during a winter week

Figure 57 above presents the substation energy demand results for the winter week. Again, it is clear that significant improvements have been made.

The Feasible Mitigation strategy scenario had a weekly energy demand of 15.2MWh which is 42% lower than the base case weekly energy load which was 26.3MWh. This is a very significant reduction in energy demand and shows the benefit of applying the mitigation strategy in reducing substation consumption. It also shows how many marginal gains from making the changes, as discussed in the sensitivity study section of this report (section 4.4), has resulted in a large and significant gain.

This investigation also showed that there was little difference in substation weekly energy consumption between the best mitigation strategy and the feasible mitigation strategy scenario. There was only a difference of approximately 0.9MWh for the week which is a 6% change.

The noteworthy outcome here is the large reduction in energy consumption following the implementation of the feasible mitigation strategy. This therefore implies that with the correct mitigation, the impact associated with widespread EV can be significantly reduced.

5 Project Conclusions

There are three sections to the project conclusion. Firstly, the overall project conclusion stating the findings from the project and outlining the mitigation strategies and the potential gains that can be realised through the implementation of the mitigation strategies.

Secondly, there is a discussion of the feasibility of implementing the mitigation strategy in to the real world.

The last section of the conclusion section will assess the shortcomings of the project due the project scope and present ideas for further work in order increase the understanding and improve the mitigation strategies.

5.1 Overall Project Conclusion

5.1.1 Impact of Widespread EV Use

It is clear that there is drive to adopt full EV instead of conventional fossil fuelled vehicles, and this study showed that there is likely to be a large widespread uptake of EV of cities around the world aim to improve urban air quality and global warming impacts by reducing GHG emissions. However, with the widespread uptake of EV, the scale to which motorists are reliant on commuting in vehicles means there are large mileage demands, and with that there are large charging demands which will have a significant impact on the urban grid.

The project used Glasgow city as the case study in which to base this investigation because Glasgow represents a typical medium sized city with a widespread types of loadings as well as old and new infrastructures reliant on supply from it's electricity network.

This project used a Microsoft Excel based data generation program developed by the University of Strathclyde and Scottish Power. It allowed an assessment of the 203 secondary substations in Glasgow, and adjustments to certain factors determining the substation dynamic loading.

The investigation determined that a notable impact of widespread EV is the significant increase to the substation peak power demand which is found to increase by 203% and weekly electrical energy demand increase of approximately 44%

compared to base case scenarios which had no EV loadings. The increased substation loading raises questions up the detrimental impact of substation transformer life span, ability of the electrical grid to supply the increased power demand, and the impact on grid power quality.

5.1.2 Sensitivity Studies and compiling a mitigation strategy

In order to determine the possible and effective methods of minimising the impacts of widespread EV charging on a urban electricity network, a sensitivity assessment of all the factors that can be altered in the program was carried out. This includes introducing micro generators such as PV and CHP, adjusting building energy efficiencies, and adjusting heating balance between EHP and CHP in order to reduce substation demand (see first column of Table 11 for a list).

A model of a ‘average substation’ was constructed in the profile generating tool, with average floor area loading types for Glasgow city, in order to fairly represent the different types of substation loads on one substation, as opposed to selecting random existing substations. This substation was used throughout the feasibility assessment and determining effective mitigation strategies.

The study showed that marginal gains can be achieved by making alteration. And when all the alterations are combined in the final mitigation strategy, the substation peak demand reduced by approximately 24%. Also, the weekly energy demand reduced by 42% in comparison to the base case scenario supporting 150 EVs. This demonstrates the potential effectiveness of the mitigation measures.

The feasibility of the different mitigation strategies was also considered and discussed further within the section 5.2 below.

5.2 Mitigation Strategy Feasibility Discussion

Although mitigation measures have been identified, it is also important to evaluate the extent to which they can feasibly be implemented in the real world. Table 11 below list the identified mitigation measures from the sensitivity study. There are two sets of mitigation measures, the first set are the optimum (or best) settings from the sensitivity study. The second are the feasible settings which are adjusted to more realistic and appropriate values for real world implementation.

Scenario Variable Name	**Best Setting**	**Best Feasible Setting**
Heat demand supplied by electrical heating (and COP)	20%, COP 3	50%, COP 3
Lighting control	100%	100%
EV charging power	7kW	22kW
PV installations	20%	10%
CHP	80%	50%
CHP heat to power ratio	1:1	1:1
EHP:CHP balance	20:80	50:50
Heating load shifting	(See section 6.1.6)	(See section 6.1.6)
Reductions to appliance demand	40%	40%
Improvements to building efficiency	100%	40%

Table 11 Summary of the best and feasible settings for mitigating widespread EV use on substation loading

This section of the conclusion provides an explanation of why the changes have been made between the ‘Best’ and ‘Feasible’ values.

- **Portion of heating demand supplied by electrical heating and COP**: The scenario aimed to have 100% of heating supplied by a mix of EHP and CHP. Therefore removing the need for gas fuelled conventional heating systems. The best setting was found to be 20%, but this required CHP of 80% which is considered too high for implementation (although this balance did produce the greatest reduction in electricity demand). So CHP is lowered to 50% and EHP increased to 50%. COP of 3 remains but is still considered to be optimistic.

- **Lighting control:** Introducing efficient lighting control systems is relatively straight forward therefore considered to be realistic for all building types. Hence why the feasible setting is also at 100%.

- **EV charging Power:** although 7kW is the best setting for mitigation. Glasgow City council are favouring the 22kW standard. Hence why it has been chosen as the feasible setting.

- **PV installations:** In Glasgow, the roof tops often do not have much spare space available for PV installation, so the amount that can be installed is limited. Even a setting of 10% is arguably too optimistic.

- **CHP Heating:** (See the first bullet point).

- **CHP heat to power ratio:** According to literature, available CHP systems can provide a ratio of 1:1 and this has also shown to be better for minimising loading than any higher ratio.

- **EHP:CHP balance:** (See the first bullet point).

- **Heating load shifting and penalty:** The best setting was found to be shifting 10% of heat load to 3 hours earlier with 0% penalty. However, the next best performing setting (by a small margin) was shifting 20% by 1 hour which is considered to be easier to implement. Also, 0% penalty is not realistic as there will always be system losses, so is changed to 20%.

- **Reduction to small appliance demand:** The amount that small appliance demand can be reduced by was limited to 40% as there will always be demand from appliances such as IT systems, sound, catering as well as other systems in the city.

- **Building efficiency improvement:** The existing architecture and infrastructure in Glasgow is very diverse in age and styles. As a result, it is very difficult to upgrade all the buildings to high efficiency standards. Therefore the integration of efficient buildings was reduced from 100% to just 40%.

5.3 Further Work Suggestions

There are a number of studies envisaged that could be carried out in order to extend this project and develop further understanding of the impact of widespread EV use on an urban electricity network, and provide further measures in order to mitigate against the impacts. The suggestions for other studies or extending this study are provided within this section of the report.

Firstly, the DPG tool does not take into account EV internal heating and air condition system loadings and the impact this has on EV battery usage, EV range and subsequent charging requirements. Future studies can look into determining the seasonal impact on EV charging requirements and the changes this makes to charging demands.

The number of EVs considered to be reflective of widespread use was 150 per substation. It should be noted that this estimation was only based on existing personal vehicle usage for commuting in Glasgow. The estimation did not take into account other motorists who may use a vehicle during the day such as school runs, public transportation, road haulage, taxi's and emergency vehicles. Further work could be carried out to assess the impact of electrification of all vehicle types on the electricity network.

EVs have been identified as an opportunity for increasing the storage capacity of the electricity network in order to support grid stabilisation. As the capacity of non-dispatchable, low carbon energy generation systems are incorporated into energy networks, this is more reliance on having a mechanism that ensures supply meets matches demand, hence stabilising the grid. Increasing electrical storage capacity is a effective means in which to do this. To summarise, electricity flow into the EV is bi-directional. Whether or not the idea of using EVs to increase storage capacity is feasible method of with regards to current vehicle usage habits is to be investigated and determined. The study could also be extended to determine if there is an opportunity to minimise the fluctuations in substation demand by using EVs as a supply as well as a consumer of electrical power. Modifying the DPG tool to incorporated bi-directional power flow (this means the not only will the EV take electricity for charging it will also be able to feed back into the network) would assist such an investigation.

The predominant aim of this investigation was to come up with mitigation measures to minimise substation peak electrical demand and energy consumption, but the investigation could be taken further by holistically evaluating environmental and energy improvement measures as opposed to only trying to minimise electrical power peaks and consumption. An example is that one of the mitigation measures was the utilisation of CHP to reduce substation electrical demand, but the increased fuel demand (and consequences of the increased fuel demand) was not taken into consideration and evaluated. Such an approach would significantly increase the scope of the project but would provide a better and more rounded understanding of the overall benefits of proposed mitigation measures.

6 Appendix

6.1 Investigation Matrices

This section of the Appendix provides the comprehensive investigation matrices regarding all the investigation sets undertaken during the project.

6.1.1 Set 1: Preliminary Substation Base Case Investigation

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
1.1	Retail demand profile study	sss002	Retail bias	winter	All	0.5	Base Case	20	1	20	3	0	0	22	0	13	0	2	0	0	20	0
1.2	Hotel demand profile study	sss135	Hotel bias	winter	All	0.5	Base Case	20	1	20	3	0	0	22	0	13	0	2	0	0	20	0
1.3	Bar/Club demand profile study	sss179	Bar/ Club bias	winter	All	0.5	Base Case	20	1	20	3	0	0	22	0	13	0	2	0	0	20	0
1.4	Rest. demand profile study	sss002	Restauraunt bias	winter	All	0.5	Base Case	20	1	20	3	0	0	22	0	13	0	2	0	0	20	0
1.5	Office demand profile study	sss171	Office bias	winter	All	0.5	Base Case	20	1	20	3	0	0	22	0	13	0	2	0	0	20	0
1.6	Flat demand profile study	sss153	Flat bias	winter	All	0.5	Base Case	20	1	20	3	0	0	22	0	13	0	2	0	0	20	0
1.7	Average substation study	AVE	All	winter	All	0.5	Base Case	20	1	20	3	0	0	22	0	13	0	2	0	0	20	0

6.1.2 Set 2: EV Charging Impact Investigation

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
2.1	Impact of 0 EVs	AVE	winter	All	0.5	Base Case	20	1	20	3	0	0	22	0	13	0	2	0	0	20	0	0
2.2	Impact of 50 EVs	AVE	winter	All	0.5	Base Case	20	1	20	3	0	50	22	0	13	0	2	0	0	20	0	0
2.3	Impact of 100 EVs	AVE	winter	All	0.5	Base Case	20	1	20	3	0	100	22	0	13	0	2	0	0	20	0	0
2.4	Impact of 150 EVs	AVE	winter	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0

6.1.3 Set 3: FES ‘Gone Green’ Scenario Investigation

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
3.1	Impact of 0 EVs	AVE	W	All	0.5	Gone Green	50	3	50	3	50	0	22	5	13	25	2	-3	40	20	-25	40
3.2	Impact of 50 EVs	AVE	W	All	0.5	Gone Green	50	3	50	3	50	50	22	5	13	25	2	-3	40	20	-25	40
3.3	Impact of 100 EVs	AVE	W	All	0.5	Gone Green	50	3	50	3	50	100	22	5	13	25	2	-3	40	20	-25	40
3.4	Impact of 150 EVs	AVE	winter	All	0.5	Gone Green	50	3	50	3	50	150	22	5	13	25	2	-3	40	20	-25	40

6.1.4 Set 4: Sensitivity Assessment

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
Electric Heating Sensitivity Study - COP 1																						
4.1.1	Electric Heating - 0%-COP 1	AVE	W	All	0.5	Base Case	0	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.1.2	Electric Heating - 25%-COP 1	AVE	W	All	0.5	Base Case	25	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.1.3	Electric Heating - 50%-COP 1	AVE	W	All	0.5	Base Case	50	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.1.4	Electric Heating - 75%-COP 1	AVE	W	All	0.5	Base Case	75	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.1.5	Electric Heating - 100%-COP 1	AVE	W	All	0.5	Base Case	100	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
Electric Heating Sensitivity Study - COP 3																						
4.1.6	Electric Heating - 0%-COP 3	AVE	W	All	0.5	Base Case	0	3	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.1.7	Electric Heating - 25%-COP 3	AVE	W	All	0.5	Base Case	25	3	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.1.8	Electric Heating - 50%-COP 3	AVE	W	All	0.5	Base Case	50	3	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.1.9	Electric Heating - 75%-COP 3	AVE	W	All	0.5	Base Case	75	3	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.1.10	Electric Heating - 100%-COP 3	AVE	W	All	0.5	Base Case	100	3	20	3	0	150	22	0	13	0	2	0	0	20	0	0
Efficient Lighting Sensitivity Study																						
4.2.1	Efficient Lighting - 0%	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.2.2	Efficient Lighting - 25%	AVE	W	All	0.5	Base Case	20	1	20	3	25	150	22	0	13	0	2	0	0	20	0	0
4.2.3	Efficient Lighting - 50%	AVE	W	All	0.5	Base Case	20	1	20	3	50	150	22	0	13	0	2	0	0	20	0	0
4.2.4	Efficient Lighting - 75%	AVE	W	All	0.5	Base Case	20	1	20	3	75	150	22	0	13	0	2	0	0	20	0	0

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
4.2.5	Efficient Lighting - 100%	AVE	W	All	0.5	Base Case	20	1	20	3	100	150	22	0	13	0	2	0	0	20	0	0
EV Charging Power Sensitivity Study																						
4.3.1	EV charging power 7kW	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	7	0	13	0	2	0	0	20	0	0
4.3.2	EV charging power 22kW	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.3.3	EV charging power 50kW	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	50	0	13	0	2	0	0	20	0	0
4.3.4	Tesla Charge Power 120 kW	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	120	0	13	0	2	0	0	20	0	0
PV Installation Sensitivity Study																						
4.4.1	PV installation - 0 m2	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.4.2	PV installation - 5 m2	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	5	13	0	2	0	0	20	0	0
4.4.3	PV installation - 10 m2	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	10	13	0	2	0	0	20	0	0
4.4.4	PV installation - 15 m2	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	15	13	0	2	0	0	20	0	0
4.4.5	PV installation - 20 m2	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	20	13	0	2	0	0	20	0	0
CHP Installation Sensitivity Study																						
4.5.1	CHP - 0% of total heating	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.5.2	CHP - 25% of total heating	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	25	2	0	0	20	0	0
4.5.3	CHP - 50% of total heating	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	50	2	0	0	20	0	0
4.5.4	CHP - 75% of total heating	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	75	2	0	0	20	0	0
4.5.5	CHP - 100% of total	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	100	2	0	0	20	0	0

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
	heating																					
CHP Installation Sensitivity Study (adjusting heat to power ratio)																						
4.6.1	CHP heating to power ratio:1	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	25	1	0	0	20	0	0
4.6.2	CHP heating to power ratio:2	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	25	2	0	0	20	0	0
4.6.3	CHP heating to power ratio:3	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	25	3	0	0	20	0	0
4.6.4	CHP heating to power ratio:4	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	25	4	0	0	20	0	0
CHP and EHP Share Sensitivity Study																						
4.7.1	CHP and EHP 20:80	AVE	W	All	0.5	Base Case	20	3	20	3	0	150	22	0	13	80	2	0	0	20	0	0
4.7.2	CHP and EHP 50:50	AVE	W	All	0.5	Base Case	50	3	20	3	0	150	22	0	13	50	2	0	0	20	0	0
4.7.3	CHP and EHP 80:20	AVE	W	All	0.5	Base Case	80	3	20	3	0	150	22	0	13	20	2	0	0	20	0	0
Shifting Heating Loads																						
4.8.1	shift loads - base case – no shift	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	0	0	0
4.8.2	shift 10% heating back 1hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-1	10	20	0	0
4.8.3	shift 20% heating back 1hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-1	20	20	0	0
4.8.4	shift 30% heating back 1hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-1	30	20	0	0
4.8.5	shift 40% heating back 1hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-1	40	20	0	0
4.8.6	shift 10% heating back 2hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-2	10	20	0	0
4.8.7	shift 20% heating back 2hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-2	20	20	0	0

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
4.8.8	shift 30% heating back 2hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-2	30	20	0	0
4.8.9	shift 40% heating back 2hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-2	40	20	0	0
4.8.10	shift 10% heating back 3hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-3	10	20	0	0
4.8.11	shift 20% heating back 3hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-3	20	20	0	0
4.8.12	shift 30% heating back 3hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-3	30	20	0	0
4.8.13	shift 40% heating back 3hrs	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-3	40	20	0	0
4.8.14	shift -3hrs 40% 0	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-3	40	0	0	0
4.8.15	shift -3hrs 40% 10	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-3	40	10	0	0
4.8.16	shift -3hrs 40% 20	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-3	40	20	0	0
4.8.17	shift -3hrs 40% 30	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	-3	40	30	0	0
Appliance demand sensitivity study																						
4.9.1	Appliance Demand 0	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.9.2	Appliance Demand -10	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	-10	0
4.9.3	Appliance Demand -20	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	-20	0
4.9.4	Appliance Demand -30	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	-30	0
4.9.5	Appliance Demand -40	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	-40	0
4.9.6	Appliance Demand -50	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	-50	0
Building efficiency improvements sensitivity study																						

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
4.10.1	Improve Building Eff. 0%	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
4.10.2	Improve Building Eff. 20%	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	20
4.10.3	Improve Building Eff.40%	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	40
4.10.4	Improve Building Eff. 60%	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	60
4.10.5	Improve Building Eff. 80%	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	80
4.10.6	Improve Building Eff. 100%	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	100

6.1.5 Set 5: Managing EV Charging Study

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area sq. m	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
5.1	Original	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
5.2	Charge dist. between 6am-1200	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
5.3	Charge dist. between 6am-2pm	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
5.4	Charge dist. between 6am-4pm	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
5.5	Charge dist. between 6am-6pm	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
5.6	Charge dist. between 6am-8pm	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
5.7	Charge dist. between 6am-10pm	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0
5.8	Charge dist. between 6am-0000	AVE	W	All	0.5	Base Case	20	1	20	3	0	150	22	0	13	0	2	0	0	20	0	0

6.1.6 Set 6: Mitigation Strategies Assessment

Test ID	Test Name	Substation(s)	Season (W-Winter)	Demand Type	Diversity Factor	Demand Scenario - Name	Electric heating %	Electric heating COP	Electric cooling %	Electric Cooling COP	Electric lighting %	No. of electric vehicles	EV charger power kW	PV area(% of floor area)	PV efficiency %	CHP heating %	CHP heat-to-power ratio	Mean Load Shift Hours	Percentage Loads Shifted %	Mean Energy Penalty %	Change in Appliance Demand %	Building Efficiency - % of Buildings Improved
6.1	Best Mitigation	AVE	W	All	0.5	Base Case	20	3	n/a	n/a	100	150	7	20	13	80	1	-3	10	0	40	100
6.2	Feasible Mitigation	AVE	W	All	0.5	Base Case	50	3	n/a	n/a	100	150	22	10	13	50	1	-1	20	20	40	40

7 References

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