Department of Mechanical and Aerospace Engineering

Managing electric vehicle charging demand and electricity generations in the future in order to reduce greenhouse gas emission in the UK

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Copyright Declaration

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Abstract

Transportation becomes the main part of energy consumption in many countries. The number of cars on roads had risen every year, and it also leads to increase the demand on energy such as oil and natural gases which causes to raise the level of air pollution and contaminate the environment. In the United Kingdom (UK), the government which was aware of the impacts from greenhouse gas (GHG) emissions had planned to reduce 80 percent by 2050 on 1990 emission levels. Recently, the evolution of transportation by gradually shifting energy demand from fossil fuels to electricity helps to lower harmful exhaust emission. Likewise, managing and optimising the behaviour of recharging electric cars will be necessary for the UK government carbon target because of a large proportion of carbon dioxide emission from cars.

This project primarily represents the suitable period of charging electric vehicles (EVs) and include plug-in hybrid electric vehicles (PHEVs) in the UK for the future. The main objective is to minimise carbon dioxide emission (CO_2) of all cars in the UK by managing charging times of EVs. However, controlling EVs charge times can cause an increasing demand during the low carbon intensity. Therefore, the UK power system needs to manage the UK generations to supply the future EV demand, while the system still maintains CO_2 emission at the low level. Furthermore, the project also predicts the future supply and demand, then combines it with the current situation to analyse on how to optimise the future carbon emission of EVs.

More specific, the project analyses the demand profile of EVs in the UK in order to understand the characteristic of EV charge times. Then, the methodology of the project is to create and simulate the EV demand profiles with 4 different deviations to mainly charge EVs during the off-peak period. The EV demand profiles are based on the estimation of an individual EV recharging demand and the number of EVs in 2050. Meanwhile the project has made 3 different cases for managing the UK power generations to supply the future demand of EVs, including only gas (case 1), gas with wind and nuclear power (case 2), and gas with all renewables, nuclear power, and biomass (case 3).

As a result, by comparing the carbon intensity of case 1 with case 2 and 3, the UK electricity generation management helps to decrease almost 15 percent and nearly 20 percent, respectively. Whereas the simulations of the EV models with a higher deviation reduce the impact of overloading the power system at the off-peak.

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Acronym

CCC	Committee on Climate Change
CCS	Carbon Capture and Storage
CO_2	Carbon dioxide
DECC	Department of Energy and Climate Change
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gas
HEV	Hybrid Electric Vehicle
ICEV	Internal Combustion Engine Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
UK	United Kingdom

1.Introduction

1.1 Background

These day the energy consumption and transportation had increased rapidly. More people tend to travel and visit another place because roads and technologies have been developed and made it easier to access. Even though the greater transportation helps to boost economic growth, the higher demand means the higher energy that will be consumed to drive car engines. To depend on fossil fuels will release more carbon dioxide into the atmosphere which causes many problems such as air pollution and climate change.

In the UK, transportation produced around 34 percent of GHG emissions by 2017(Department for Business, Energy and Industrial Strategy, 2018). According to the UK government's policy to reduce 80 percent GHG emissions by 2050 on 1990 levels (Department of Energy and Climate Change, 2011), renewable energy and electric vehicles will play the significant roles in the electrical system and our lifestyles. Fortunately, the number of new electric car registrations in the UK rise from 3,500 in 2013 to approximately 162,000 by July 2018(Lilly C., 2018). This increasing trend on the electric cars is because they are environmental-friendly and less noise pollution. However, the UK government cannot solely rely on technology developments and market trends. Therefore, regarding how to optimise and manage electricity between demand and supply will become the essential supplement of the UK carbon emission reduction targets.

An electric car ordinarily requires to recharge a battery which depends on how much energy is consumed. For example, the Nissan Leaf 40 kWh spends around 14 hours to fully charge the battery with 3 kW home charger and takes about 6 hours to fuel the depleted battery with 7 kW home charger (Lilly C., 2018). According to the charging times of electric cars, a long period of charging the battery is likely to be one of the main constraints. Another problem is that the duration of charging electric cars is fairly limited because the low intensity of CO_2 emissions in the UK usually occurred at between late night and early morning. In addition, charging electric cars at the off-peak is unreliable because it depends on renewable energy, especially wind energy which is varied by wind speeds.

Hence, this project will estimate and analyse on how it is possible to manage the charging time of EVs to reduce GHG emissions and find suitable sources to raise the generation during the low carbon emission for the current and future periods.

1.2 Aims and Objectives

This project is established to determine the suitable time of charging EVs at the low level of carbon dioxide emission in the UK. However, when electricity demand is limited within a short of periods, the energy may be insufficient to supply electricity to recharge electric cars. To find alternative energy resources to compensate the large demand is also significant for the project. Likewise, the project has to consider how to manage generations, while understanding the feasibility of charging electric cars in the time frame. Therefore, there are three main objectives to follow;

- Find the suitable charging time of EVs at the low carbon intensity
- Manage to use the best options of generations to supply electricity at EVs charging times
- Minimise carbon intensity by controlling charging times of EVs

1.3 Methodology Overview

Project methodology is to collect the current data of electricity generation and EV demand profiles in the UK, then predicting the future demand and supply to mix with the EV demand model in order to optimise and manage charge time of EVs in the future. Hence, the data can be calculated and analysed by statistics and using fundamental mathematics. Plus, the report analyses on possible impacts that can be caused by controlling the EV demand.

The methodology of the project is as follows:

1. Understand the changes of electricity generations and EV demand profiles in the UK in order to link it with the charging period of EVs
2. Understand the carbon content in the UK and how to calculate it
3. Understand the general background of EVs such as the type of electric vehicles, the different EV companies in the UK, the level of charging from the literature review

4. Find generations that can produce power to match demands in a charging of periods
5. Share EV demand to different sources in order to reduce overburden to a single generation and reduce CO_2 emissions
6. Research on the future supply and demands on EVs
7. Add the future data with the current statistics by calculating
8. Simulate the carbon intensity of the combination between UK electricity demand and EV recharging profiles in 2050
9. Simulate the carbon intensity in two seasons; summer and winter
10. Analyse the impact on charging EVs at the period of the low carbon dioxide emission

1.4 Scope

The project will

- Scope on EVs and PHEVs in the UK
- The different levels of charging; slow, fast, and rapid in order to estimate time to charge EVs
- Collect the data of from specific sources on typical days in 2018, then using this data and essential information from previous researches to predict the future demand
- Scope on the main generations to supply electricity to the future EV demand such as gas, wind, nuclear, and solar energy.
- Investigate the carbon dioxide emissions of the UK in summer and winter
- Consider the stability of the UK power system from an increasing demand of EVs during off-peak periods
- Focus on generating EV demand profiles by a normal distribution curve with different deviations from 0.4 to 0.7.
- Investigate the impact of optimising EV charge times

2. Literature Review

2.1 Electricity Generation Profile in the UK

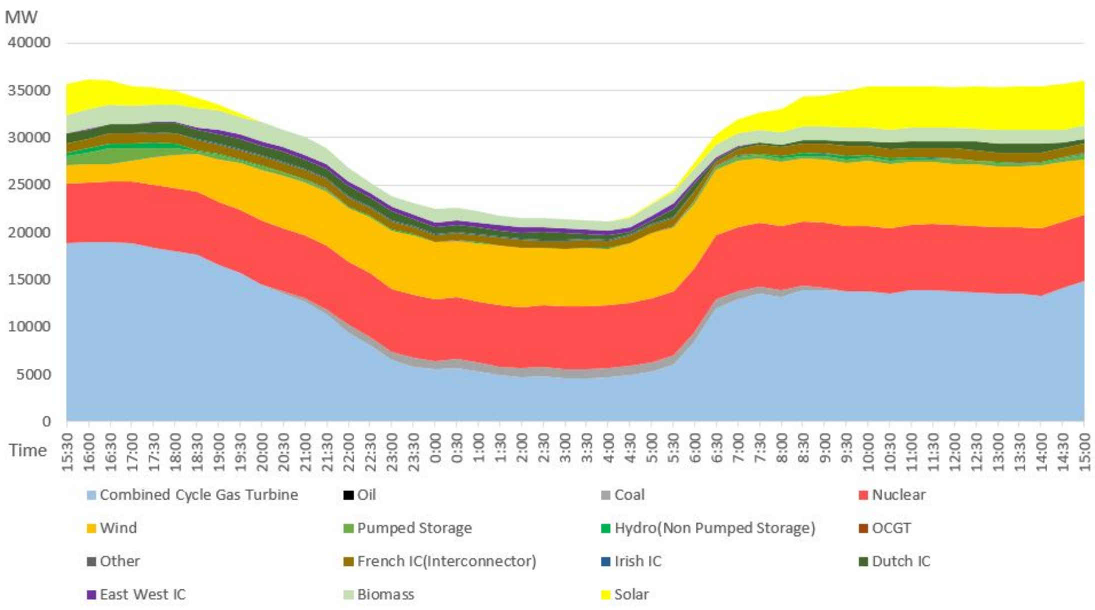


Figure 1 Electricity generation profile on typical days in the UK

In order to prepare for higher demands in the future from Electric Vehicle, the project needs to understand the characteristic of current electricity demand and generation. As it shown in Figure 1, the graph demonstrates the electricity generation by type (MW) in the UK between 19^{th} and 20^{th} June 2018. All in all, the electricity generation fluctuates over the period. There are low demands in the night time from around 22:00 h to 5:30 h, at about 22,000 MW, whereas from the morning until the evening the demand rises to a peak at approximately 35,000 MW and remains at the steady state. (Elexon Portal, 2018)

The generations in the UK consist of combined cycle gas turbine, oil, coal, nuclear, wind, solar, pumped storages, hydro power with non-pumped storage, biomass, and others. Besides, the UK imports electricity via interconnectors from French, Irish, Dutch, and East-West. This electricity profile uses generation mix data from Elexon Portal, which gives updated data every 5 minutes. Only the PV generation data is estimated by the University of Sheffield separated into 30-minute periods. Thus, to combine these two data the line graph in Figure 1 demonstrates electricity generation profile every 30 minutes.

In short, combined cycle gas turbine is the main generation as a base load during the daytime, and it also generates most electricity throughout the period. On the other hand, nuclear power and wind energy are the main sources of electricity generation at night, meanwhile combined cycle gas turbine produces less power than these two energies. Furthermore, the solar generation is one of the main proportion to generate electricity during the daytime. For the fossil generations and the interconnectors combined, the power is distributed and imported still less than nuclear, combined cycle gas turbine, wind power, and solar energy. Interestingly, biomass generate electricity mostly during the low demand.

2.2 Electric Vehicles

2.2.1 EV Introduction

Electric vehicles tend to become one of the most popular technologies for transportation around the world because it helps to reduce air pollution and noise. Likewise, EVs also decrease CO_2 emissions. Additionally, to reduce CO_2 emission more effective, the energy for EVs should be generated by renewable energy, nuclear power or other non-fossil-fuel sources.

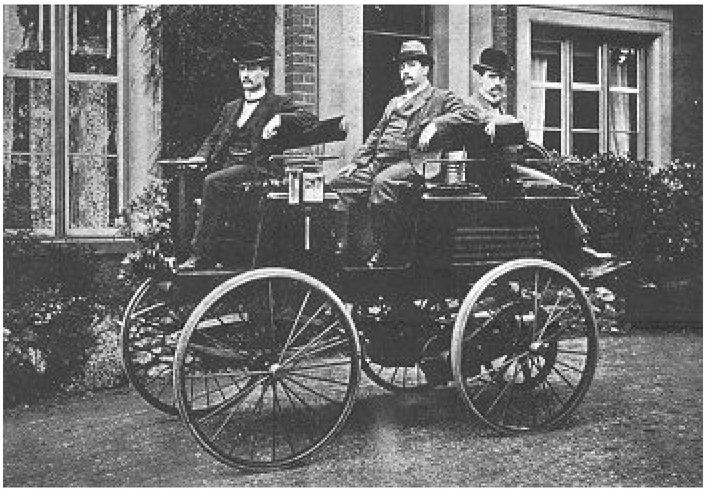


Figure 2 First Crude Electric Vehicle (US Department of Energy, 2014)

According to the US Department of Energy, the history of Electric Vehicles was first started in 1828. It was developed from a horse and buggy for transportation by Scottish inventor Robert Anderson in around 1832. After, the first crude EV in Figure 2 had successfully been debuted in the US by 1889, this new innovative attracted a lot of demand. Then, Figure 3 illustrates Electric Vehicles which used Nickel-Alkaline batteries was developed by Thomas Edison in 1901. However, the future path of EV technology was reasonably rough.

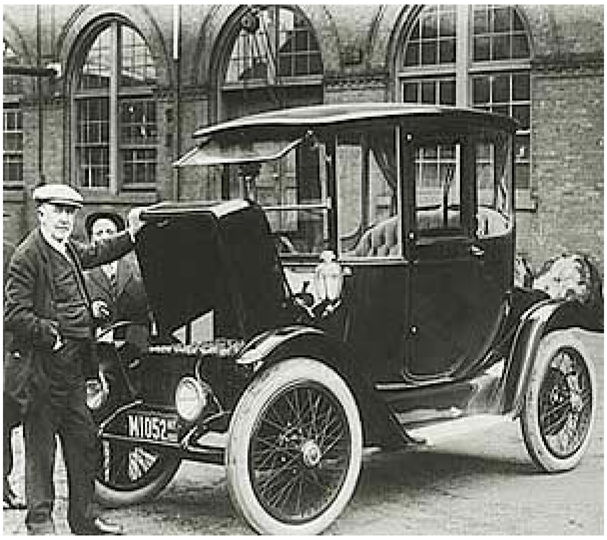


Figure 3 Electric Vehicles using Nickel Alkaline batteries by Thomas Edison (AutomoStory, 2018)

By the 1930s, EVs had nearly disappeared from the scene because the greater performance of the Internal Combustion Engine Vehicles (ICEVs) and oil prices declined (International Energy Agency, 1993). Certainly, EV technology had a tough time to emerge in the world market due to the revolution of petrol vehicles. Even though after few decades, the performance of EVs is being slowly improved such as control system, capacity of batteries, motors, and EV chargers, the costs are still expensive and their performance is not enough to run in a long distance.

Over few decades, the internal combustion engine overwhelmed EVs because fossil fuels were plentiful and cheap. But between around 1960s and 1970s, oil prices rise rapidly which create interest in EV again.

From the end of 19th century until now, EVs was grasped market attention in many countries because of increasing concerns on the environmental problems. Recently, EV technology is competitive. Many manufacturers have been developing and inventing greater and greater electric vehicles every year. Figure 4 shows one of the latest EV is Nissan Leaf (2018) with 40 kWh of batter power which has a driving range up to 235 miles New European Driving Cycle (NEDC) and the power output of motor is approximately 150 hp (Hubbard, 2018).

Figure 4 The new 2018 Nissan Leaf (CAR, 2018)

2.2.2 Types of Electric Vehicles

According to Larminie and Lowry (2012), types of Electric Vehicles are classified by how electricity is used as their power source. In Figure 5, the picture demonstrates three different types of Electric Vehicles. These are Hybrid Electric Vehicles (HEVs) which is in the orange background, Plug-in Hybrid Electric Vehicles (PHEVs) in the middle, and Battery Electric Vehicles (BEVs or EVs) on the right-hand side.

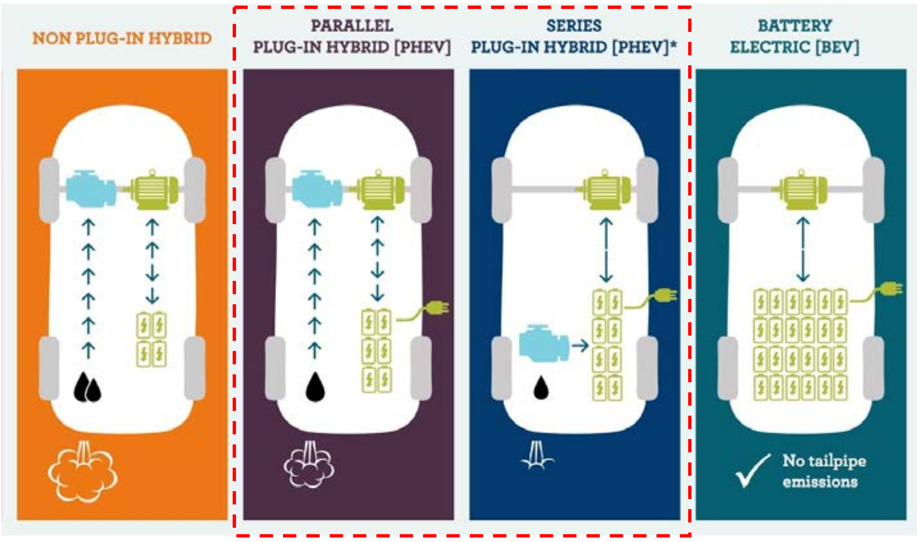


Figure 5 Three types of Electric Vehicles (Larminie and Lowry, 2012)

1. Hybrid Electric Vehicles (HEVs)

HEVs are powered by two-part drive systems, an electric drive and an internal combustion engine. While driving an HEV, the batteries can be electrified by using their braking system which is called "Regenerative Braking." This process helps to charge batteries and reduce the vehicle's speed. Furthermore, the HEV has an internal computer which helps to control the two motors in the vehicle efficiently and economically. At the initial speed, the HEV uses the electric motor, then the car engine changes to the petrol when the vehicle reaches the cut-in speed.

2. Plug-in Hybrid Electric Vehicles (PHEVs)

PHEVs have a similar concept to HEVs, but they have bigger electrical drives and battery capacity and smaller the internal combustion engines than HEVs. Moreover, PHEVs have a receptacle to charged electricity at any stations so that these vehicles are almost able to drive by electricity only. Also, PHEVs have two different categories; series and parallel (Lake R., 2017).

In a Series PHEV, only electric motor connects and moves to the vehicle wheels. This electric motor can also gain electricity from either a battery or a generator, which is generated by an internal combustion engine. In addition, a Series PHEV has a controller to switch the system between the battery and the generator.

On the other hand, a Parallel PHEV has both an internal combustion engine and an electric motor that work together to move the car. These two engines are connected to the drive shaft. The electric motor uses power from the battery to turn the vehicle wheels, while the gasoline engine consumes fossil fuels. Also, a Parallel PHEV has a controller as the series.

3. Battery Electric Vehicles (BEVs or EVs)

A BEV is a pure electric vehicle which does not have a gasoline engine. Thus, it has large battery packs that can store and charge a large amount of energy. This battery power is sent to an electric motor to drive the vehicle. A BEV can be recharged electrical power from a receptacle, electric vehicle charging stations or an external source. A BEV, however, still have some disadvantages when it compares with other types such as long charging time, limited range of speed, and higher cost of components (Veneri, 2017).

2.2.3 EV Charging Speeds

Each EV has a different capacity of charging speed and a connector. Charging time can be estimated by EV charging capacities, but it can vary by the state of the battery (how much energy left in a battery), the maximum charging rate, and the ambient temperature. EVs charge power in term of kilo-Watt (kW). Moreover, according to Lilly (2017), EV charging speeds can be separated into three levels; slow, fast, and rapid.

1. Slow charging is commonly used to charge EVs at home during the night time. Slow charging points can charge up to 3.6 kW and 16 A, and they can also be found at public points and workplace. Charging times depend on unit vehicle and speed, normally it takes around 6 to 12 hours to fully charge an EV battery.
2. The rate of fast chargers is basically at either 7 kW or 22 kW with single phase or three phases 32 A. A 7-kW charger can charge between 3 to 5 hours, while a 22-kW charger takes around 1 or 2 hours. These chargers can be seen at shopping centres, supermarkets, car parks or a place where an EV will be likely parked in a few hours.
3. Rapid chargers can recharge an 80 percent of a battery within approximately half an hour which are the quickest method to charge an EV. These chargers can be found in locations near main roads or motorway services. Besides, rapid chargers can supply high power alternating current (AC) and direct current (DC) to charge a battery. Rapid DC chargers deliver electricity at up to 50 kW with 125 A. In addition, rapid DC superchargers from Tesla provide power at up to 120 kW. On the other side, rapid AC chargers deliver electricity at up to 43 kW with three phases 63 A.

2.3 Trend of EV Stations in the UK

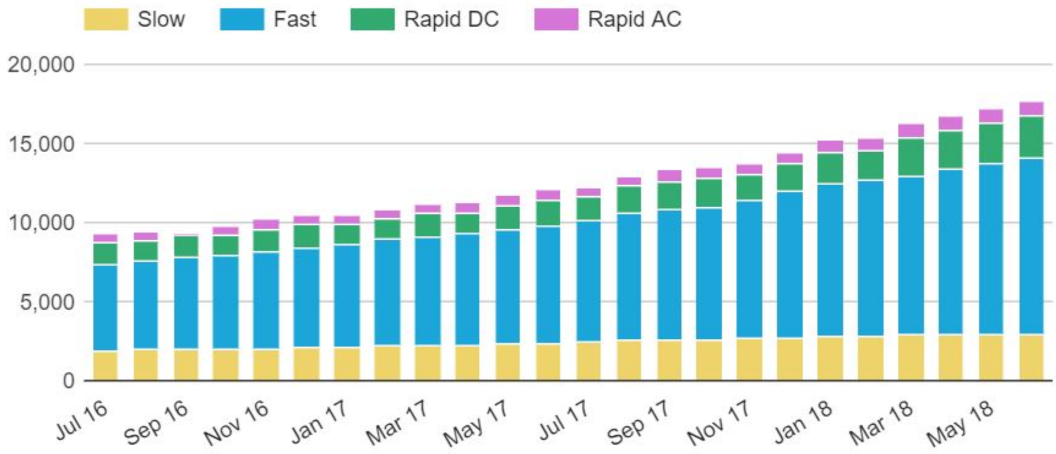


Figure 6 The number of charging stations in the UK by different charger speeds (Zap-Map, 2018)

In Figure 6, the bar chart shows the proportion of different charger speeds in the UK from July 2016 to June 2018. Overall, there was an increasing trend for the charging points in the UK. Every month the number of each charging speeds grew gradually. Particularly, the fast charger in the blue bar was the most popular charging stations throughout the period. Also, the number of the fast charger increased by more than doubled from about 5,400 in 2016 to over 11,000 in 2018. The second highest charging unit was the slow charger in the yellow bar. However, the number of slow charging stations in the UK was much lower than the fast charging stations. It started rising slowly over the period from around 1, 900 to 3,000 stations. For the minor proportions which are rapid DC in the green bar and AC in the pink bar, the number of these two charging stations combined were nearly as equal as the slow charging points.

Figure 7 illustrates that public charge stations have risen in the UK with above 8,000 charge points placed at higher than 3,100 locations in 2015 (Element Energy, 2015). The public charge points are divided into four categories which include slow (3kW, AC), fast (7kW, AC), fast (22kW AC), and rapid (43-50kW DC). It can be seen that the number of the public point in Great Britain is considerably high. Overall, the charge points were extremely intensive in the city area. The greatest figures of charge point are fast (7kW, AC) which is installed on-street. While the number of slow and rapid charge spots are fairly high in the big city like London. However, Northern Ireland has the largest fast charge stations (22kW, AC).

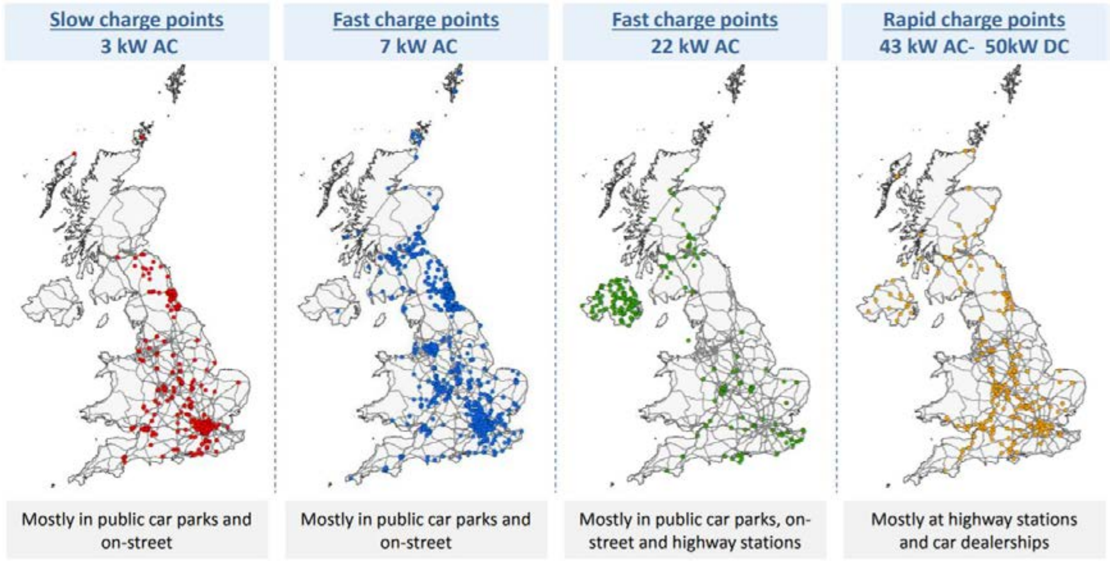


Figure 7 Public charging stations has increased in the UK over 8,000 charge points at more than 3,100 locations (Element Energy, 2015)

2.4 Models of Recharging Profiles

Morrow et al. (2008) estimated the recharging profiles of the 2001 US National Household Travel Survey which focused on daily distances and individual trips by the US Department of Energy. This research described that there are three typical EV charging scenarios which include charging at a home, a commercial facility, and an apartment. On the other side, Kang and Recker (2009) had created four charging scenarios which include the scenario at the end of a travel day, controlled charging, uncontrolled home, publicly available electricity recharging. This theory based on vehicle use and charging demand assumptions from the 2000-2001 California Statewide Household Travel Survey. First, they presumed that at the end of the day from traveling charging scenario is when vehicles were electrified after finishing a trip on the periods. For the controlled charging, EVs were restricted to recharge after 22.00 h. In contrast, the uncontrolled home scenario is when EVs were charged after coming back home on an evening. Lastly, publicly available electricity recharging was defined when EVs were recharged in a public area.

Likewise, a research on the impacts of EVs on the Western Australian electricity grid showed three recharging scenarios in the different time. (Mullan et al, 2011). The first scenario was to charge EVs from 16.00 h to 23.00 h. Another scenario was assumed to be at night between 22.00 h to 7.30 h. The last scenario was the controlled charging EVs between 19.30 h and 02.00 h.

Similar to Kang and Recker, Wang et al. (2011) made four PHEV charging scenarios for the power system in Illinois; smart charging, smarting charging with demand response, 3 hours delayed charging, and unconstrained charging. EVs in these four scenarios were recharged during off-peak periods on the power system.

Weiller (2011) mentioned that the EV charging time can be affected by location such as home, public areas, or the workplace. The research described the changes of PHEV recharging profiles in different locations in the United States. Moreover, this study estimated that daily electricity demand will increase from 24 to 29 percent because of recharging PHEV at home.

Another survey to point out is that Robinson et al. (2013) researched on the recharging behaviour of EV in the north east of England. They had collected the data from 44 EVs in those areas for six months and drawn EV recharging profile on different types of users and different locations. The user types of EV drivers include private users, organisation individual, and organisation pool, whereas the location of EV recharging is at home, work, public, and other. Figure 8 represents one of the recharging scenarios which is categorised by locations. Moreover, Robinson explains that the highest recharging event is at work which is between around 9:00 h and 10:00 h. For home and other, the peaks occurred at about an evening. While public also had a morning peak like work, but it was the lowest frequent of EV recharging.

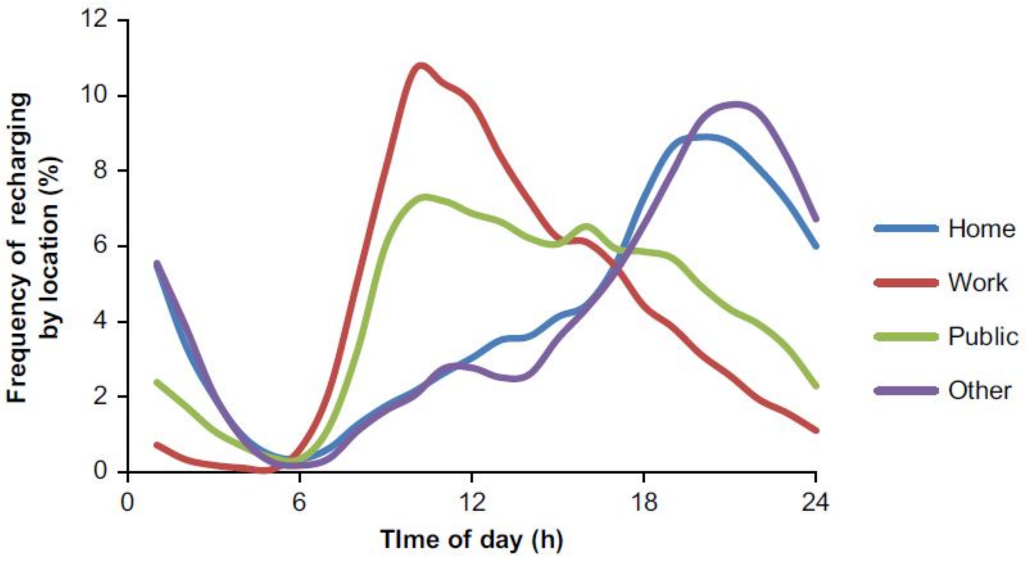


Figure 8 EV recharging profiles by different charging locations on a typical day (Aunedi et al, 2014)

Figure 9 represents the residential EV charging demand of an individual vehicle from 54 vehicles in London from 2th April 2013 to 2th April 2014. Furthermore, most chargers in the research is 3.7 kW, yet some areas are installed slow chargers and 7.4 kW chargers. Aunedi et al. (2014) show that most vehicles recharged at about 3.7 kW. By estimating on an individual vehicle, Aunedi et al. (2014) said that the charging pattern varies on weekly and daily which this may be hard to predict a single EV demand profile.

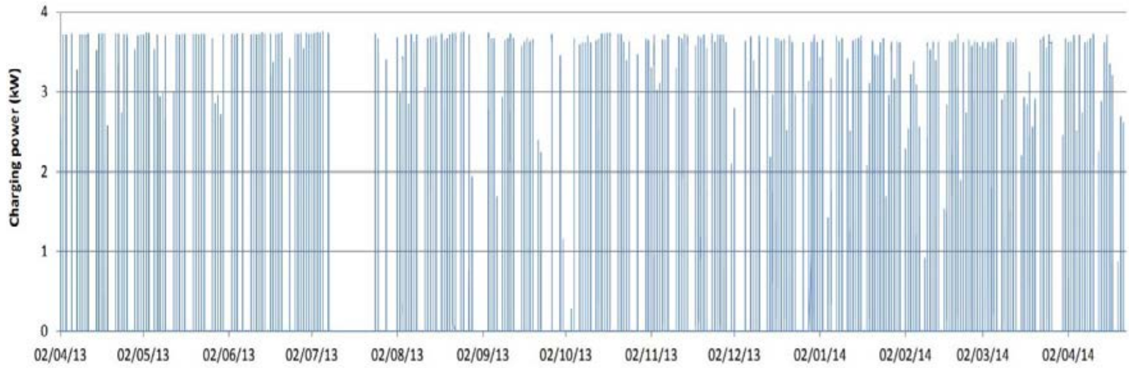


Figure 9 Charging demand profile of a residential EV in London between 2013 and 2014 (Aunedi et al, 2014)

Additionally, Aunedi et al. (2014) also present the data of residential charging events as illustrated in Figure 10. The charging event is regarded as the energy in batteries and time to recharging the power. In Figure 10, an individual vehicle spent around 2.5 hours to fully charge batteries, and it consumed 6.6 kWh which has the consumption rate at approximately 0.12 kW/ minute.

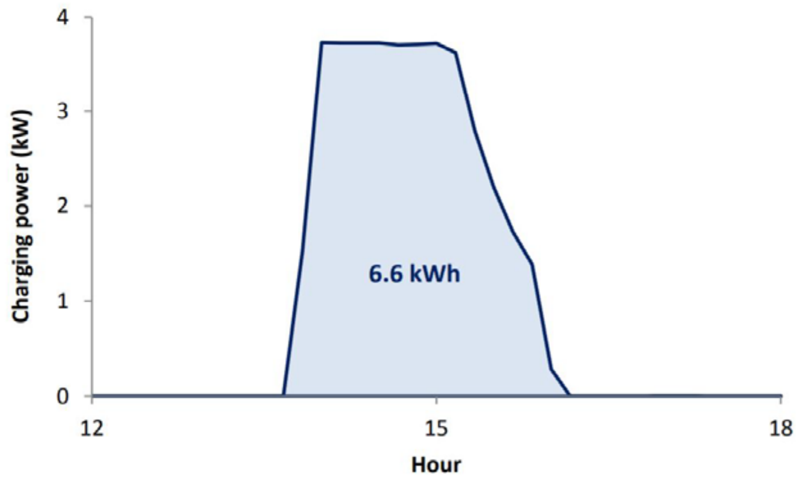


Figure 10 Charging a battery of an EV on a typical period to full capacity (Aunedi et al, 2014)

2.4.1 Charging Duration of EV

The duration of EV recharging demand helps to comprehend the feasibility to charge EVs within a short of periods. Aunedi et al recorded the data from 54 residential samples that used a Nissan Leaf with 24 kWh and 16 commercial stations with 1-phase meters on EV drivers in London in 2014 to gain the percentage of EV charging duration as shown in Figure 11 and Figure 12.

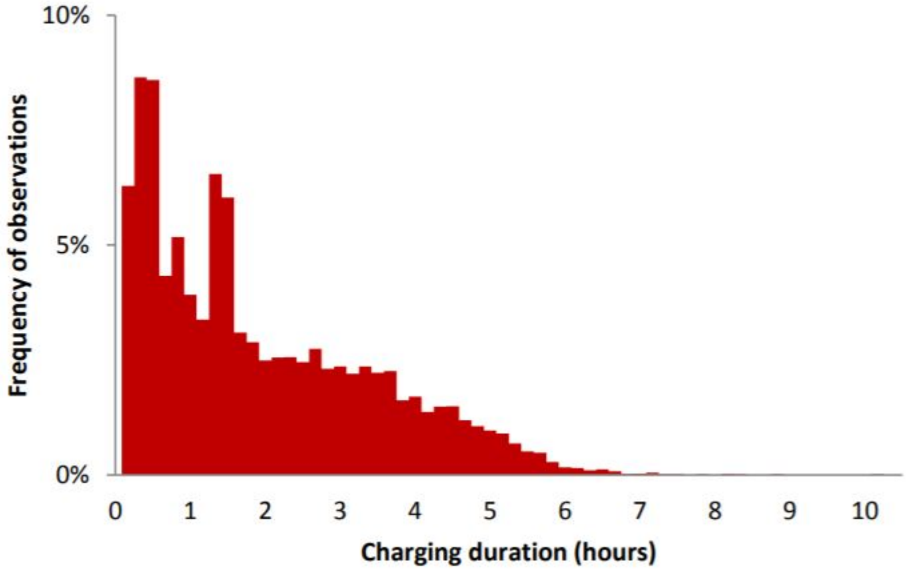


Figure 11 The frequency of EV charging duration for residential samples in London (Aunedi et al, 2014)

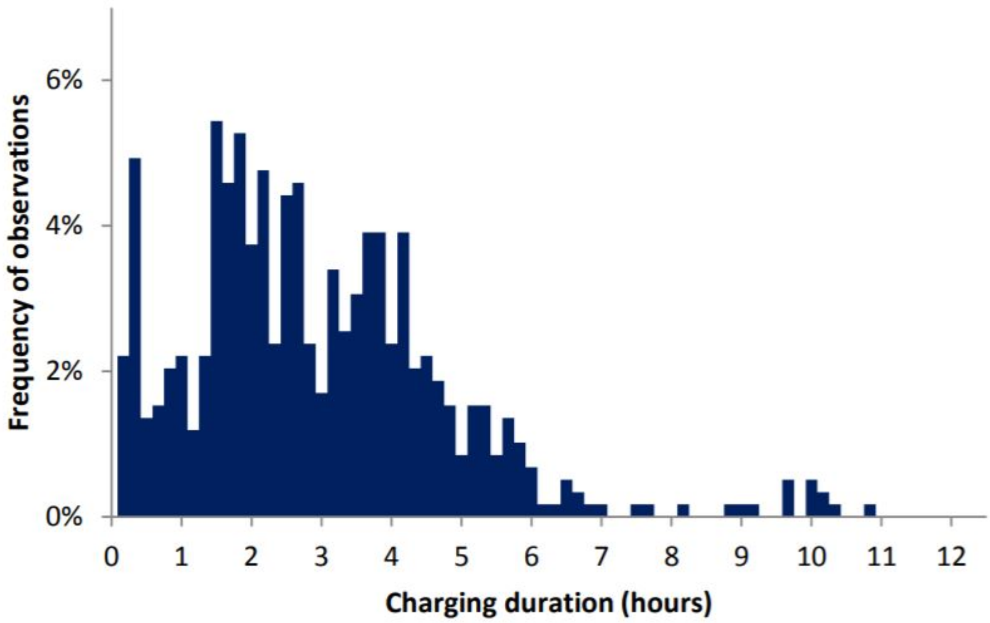


Figure 12 The frequency of EV charging duration for commercial samples in London (Aunedi et al, 2014)

The statistic shows that most residential users spent lower than 5 hours, and the more frequent charging was around half an hour and one and a half hour (Figure 11). On the other hand, the majority of commercial drivers tended to spend around 2 hours to charge EVs, and about 5 percent of commercial drivers used more than 5 hours to fill a battery.

2.4.2 EV Driving Distance

The distance of EVs can explain the behaviour of drivers and estimate how much the energy will be consumed. The survey on the EV driving distance of residential and commercial drivers is shown in Figure 13 and 14 by Aunedi et al, 2014. This research had collected the data from individual trips in London. The total trips for the residential model were 10,857, whereas the commercial model was 2,597 trips.

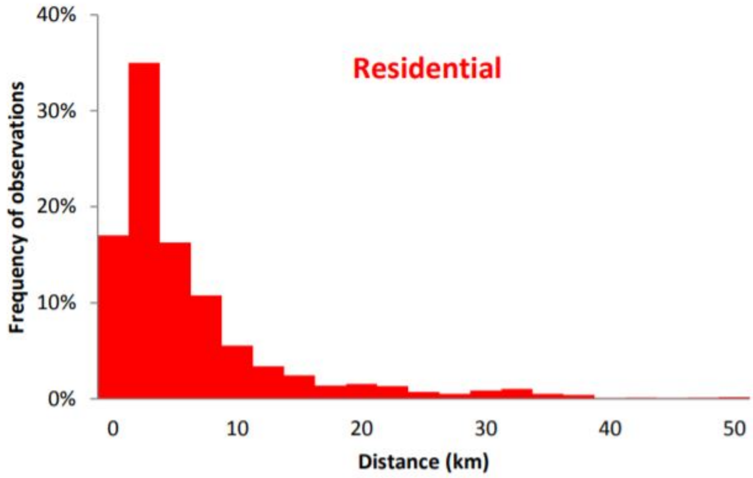


Figure 13 The frequency of distance for residential samples in London (Aunedi et al, 2014)

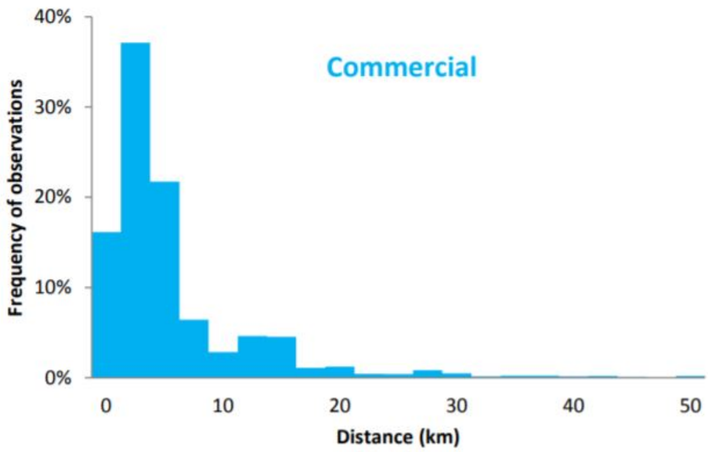


Figure 14 The frequency of distance for commercial samples in London (Aunedi et al, 2014)

As it illustrated in Figure 13 and 14, most of the both residential and commercial samples drove EVs less than 10 kilometres. Also, most people in London drove EVs around 4 kilometres. Meanwhile, there was less than 5 percent that users drove more than 24 kilometres for residential users and 20 kilometres for commercial users.

2.5 Prediction on EV demand in the UK

Before mixing EV demand with the UK electricity demand, it is important to understand and estimate the EV demand in the future in order to minimise the impacts and improve the potential of UK power system along with the environmental-friendly as the UK government policy to reduce 80% of greenhouse gas emissions by 2050 on 1990 levels.

Vallely L. (2017) described that the demand on EVs in the UK has risen swiftly. Also, the estimation from National Grid expected around 9 million EVs will be on roads in 2030, and EVs sales may reach 90% of all cars in the UK by 2050. In this case, the EV demand could increase the current peak of electricity demand to nearly 80 GW in 2050. While the forecast from Chargemaster (2018) anticipated that the UK will have 1 million EVs on roads by 2022. Then the new EV registrations in the UK will grow to 60 percent of all cars. By 2040, the scenario forecasts every car in the UK will be EVs. According to the Future Energy Scenarios, the National Grid forecasted that the number of EVs on UK roads could grow to 36 million vehicles by 2040 (Evans S., 2018).

2.6 Expectation on Energy Demand in the UK in 2050

Spataru et al. (2013) had made two scenarios which include “ZORBA” and “KALINKA” for the prediction on the UK energy demand from 2020 to 2050. Both scenarios were created by using the Department of Energy and Climate Change (DECC) 2050 Pathway Calculator. ZORBA scenario was generated to secure energy resources in the long term and preserve the environment which mainly supported renewable energy, energy storage, and nuclear power. On the one side, KALINKA scenario secured energy resources in a short-term and improved new technology such as using fossil fuels with Carbon Capture and Storage (CCS) in order to reduce the GHG emissions.

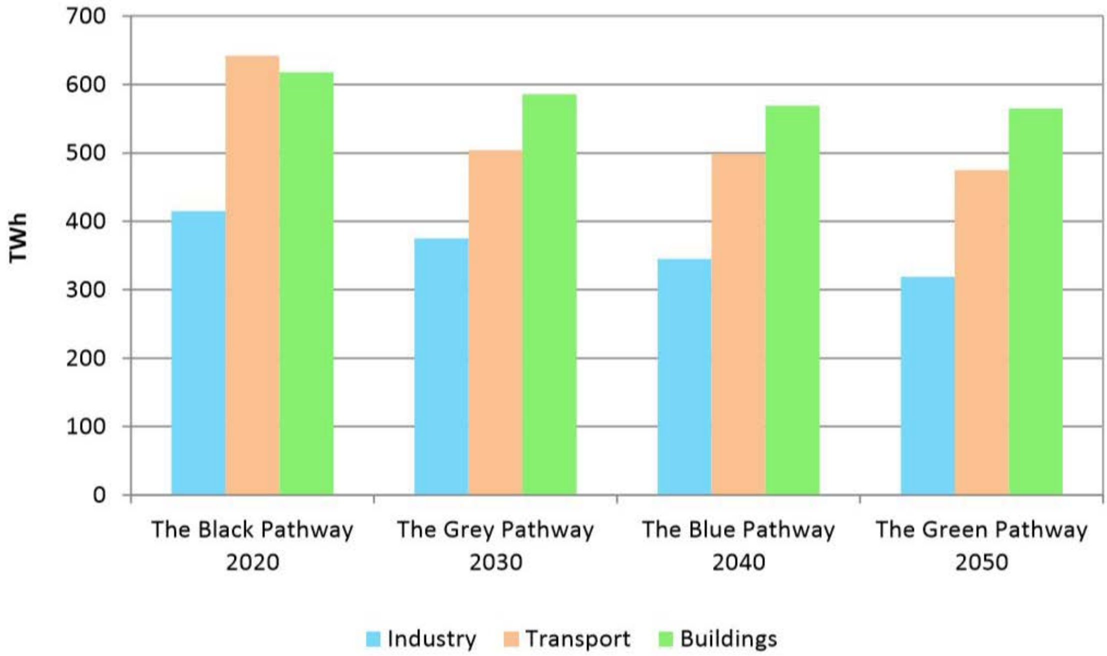


Figure 15 The estimation on the UK energy demand for industry, transport, and building from 2020 to 2050 (Spataru et al., 2013)

In addition, Spataru et al. (2013) described that the total energy demand in the UK by 2050 is predicted to be around 1,359 TWh/yr which accounts for 26 percent of energy reduction from 2020 to 2050.

In Figure 15, the bar charts compare the UK energy demand in three different sectors between 2020 and 2050. In 2020, the highest energy demand is transport which is over 620 TWh, and the building is the second highest energy demand. While industry demand starts at only around 410 TWh. After a decade, the energy demand for transport drops dramatically to 500 TWh, whereas building decreases slightly and becomes the greatest demand. For the industry, the energy demand reduces below 400 TWh. For the last two decades, the energy demand in all three sectors decreases a little bit or about 10 to 30 TWh each decade.

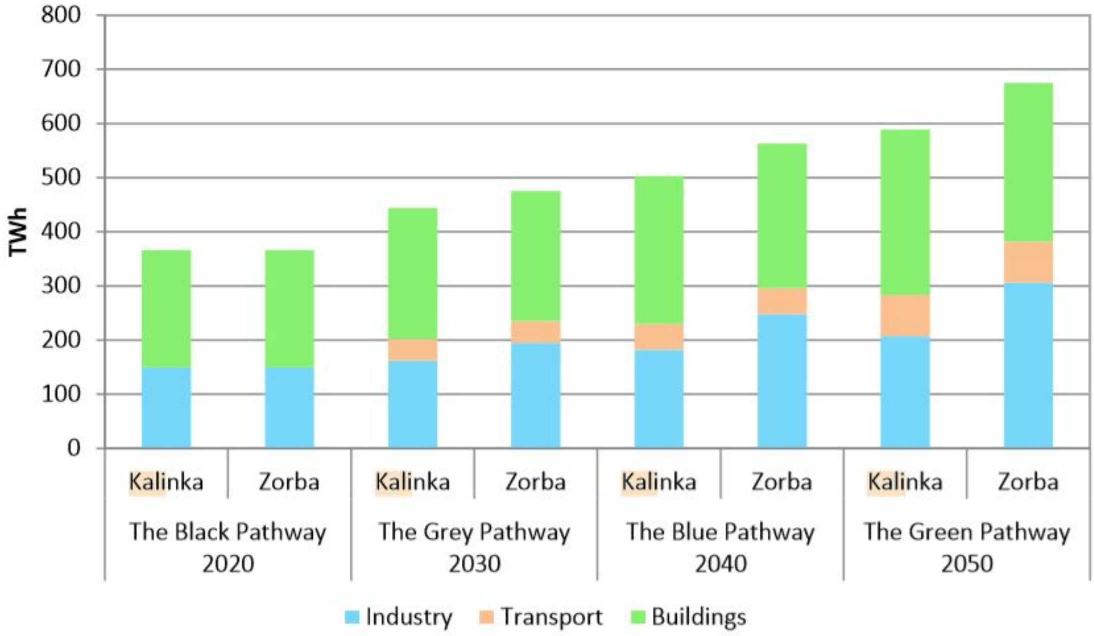


Figure 16 The UK electricity demand of Zorba and Kalinka scenarios between 2020 and 2050 (Spataru et al., 2013)

In the Black Pathway or 2020, the electricity demand for Zorba and Kalinka remains the same values at approximately 370 TWh as it presented in 16. Also, there is no demand from transport for both scenarios in 2020. Then, the total electricity demand for Zorba scenario increases more than Kalinka due to the higher demand from industry in 2030, plus adding the demand from transport in two scenarios. After that, the total electricity demand in both cases rises considerably to about 590 TWh for Kalinka and about 680 TWh for Zorba in 2050. In every decade from 2030, the proportion of electricity demand from transport in both scenarios is getting wider and wider, and it almost reaches 100 TWh.

2.7 Potential Impact of EV Demand

Zhang et al. (2010) researched on optimising power systems from EV charging demand. They made four scenarios by different levels of EV penetrations. Also, they found that the controlled EV demand may not be able to use completely in a practical way because drivers may have to drive EVs during the controlled periods.

On the other hand, Qian K. and Zhou C. (2011) created the methodology to analyse the EV demand in the distribution system. They also made four scenarios for the EV charging demand which consist of uncontrolled EV domestic demand, uncontrolled EV domestic demand at the off-peak time, “smart” EV domestic demand, and uncontrolled

EV recharging demand at a workplace in order to regulate EV charging loads in the UK. For example, the result of uncontrolled EV domestic demand shows that if EVs penetrate 10 percent of energy demand, the daily peak load can go up to 17.9 percent. Also, if there is 20 percent market penetration of EVs, the peak demand may rise to 35.8 percent. Figure 17 demonstrates the uncontrolled EV recharging demand with 0, 10, and 20 percent market penetration in winter, meanwhile Figure18 presents the controlled (smart charging) EV demand with the same penetration levels.

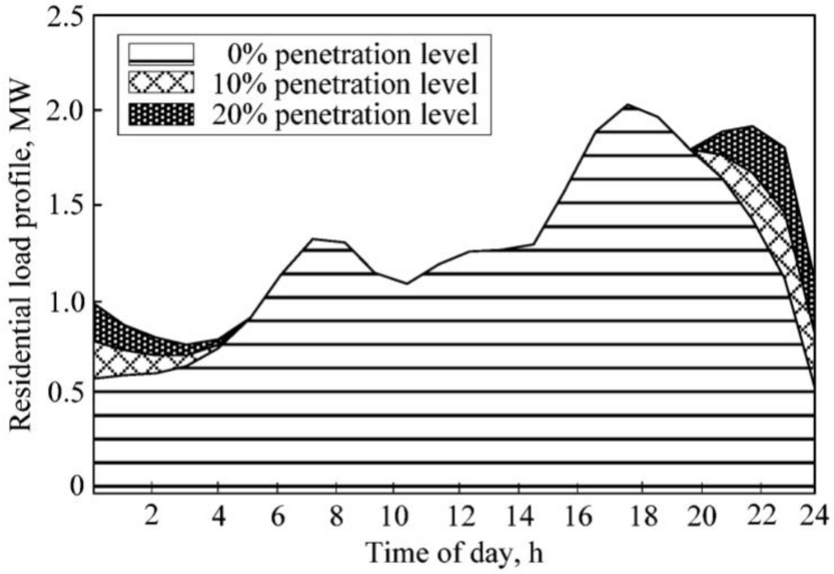


Figure 17 The UK electricity demand and uncontrolled EV demand at off-peak periods on a typical day in winter (Qian K. and Zhou C., 2011)

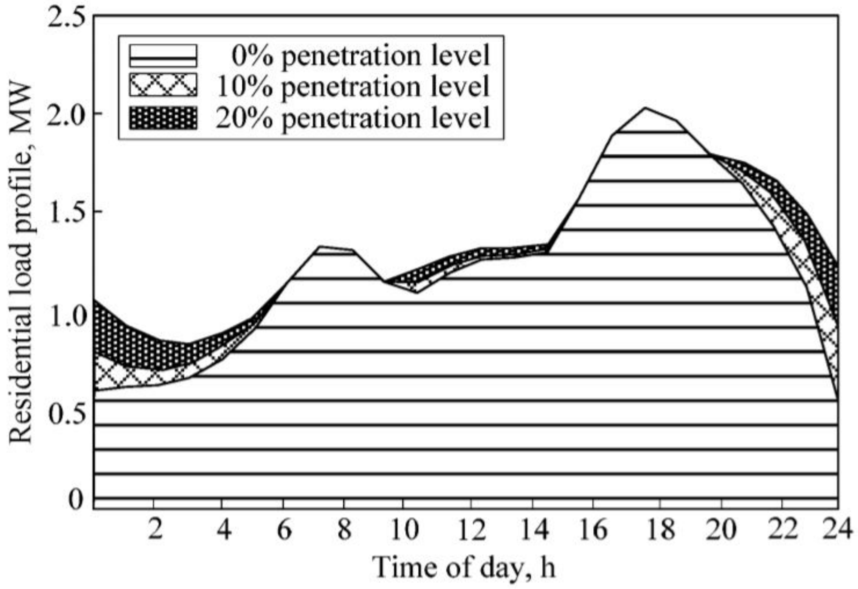


Figure 18 The UK electricity demand and smart EV demand on a typical day in winter (Qian K. and Zhou C., 2011)

3 Methodology

3.1 Overview

The higher demands from EVs will raise electricity demand at on-peak. This problem will lead to increase a burden on existing generations. Therefore, if the UK government overlooks the management of electricity demand and supply, power plants may spend a lot of money for more power generation capacity. Also, local power grids may overload if a high demand to charge EV occurs during a peak time. (Jansen et al., 2010; Kemp et al., 2010; McCarthy and Yang, 2010)

Basically, charging EVs should be managed to distribute electricity demand equally throughout a day. Kemp explains that charging EVs during the off-peak period decreases the cost of investment in power generations, meanwhile it helps to reduce demands on local power distribution networks. Plus, the huge advantage of off-peak recharging of EVs is that it reduces the carbon content of the generations to charge EVs.

Data Collection

The project has collected the data of the UK electricity supply on typical days in summer and winter, 2018 from Elexon Portal and the University of Sheffield. In addition, the uncontrolled EV demand profile is made from the actual research of Energy Policy, 2013. Also, the future estimation of the EV demand is based on Element Energy and a survey of Aunedi M et al., while UK electricity demand is from the UK 2050 Calculator.

The UK electricity generations in summer are shown in Figure 1, and the winter data is presented in Figure 19 below. On the other hand, the other data will demonstrate in the following steps.

Winter Data

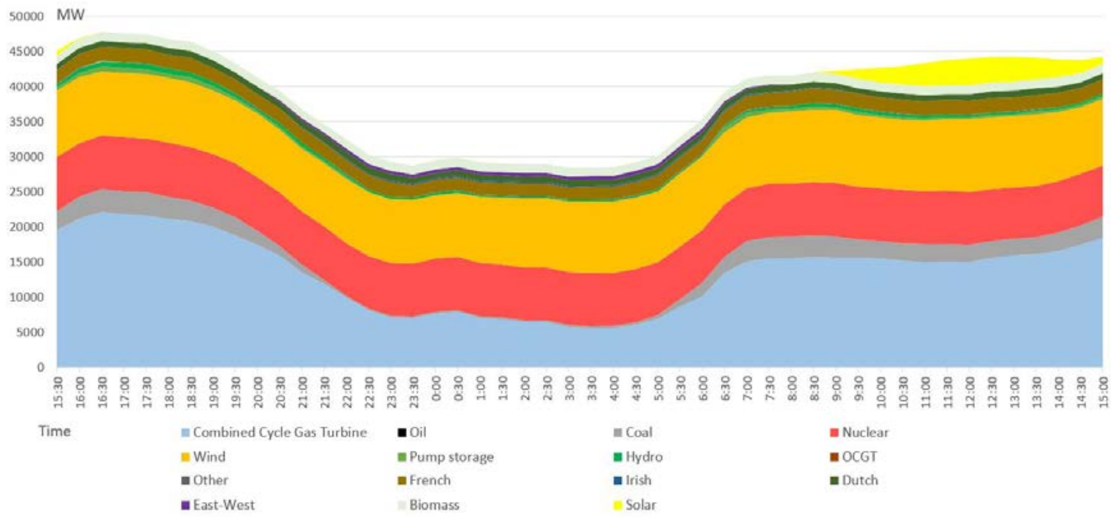


Figure 19 The UK electricity generation profile from 15th to 16th of January, 2018

As it shown in Figure 19, the UK mixed generations on typical days in winter had a similar curve as summer in Figure 1 which the high demand happened on the daytime, and the low demand occurred at night.

By comparing the electricity generations between two seasons in 2018, the demand in winter had increased by around 5,000 MW (Figure 19) over the time frame.

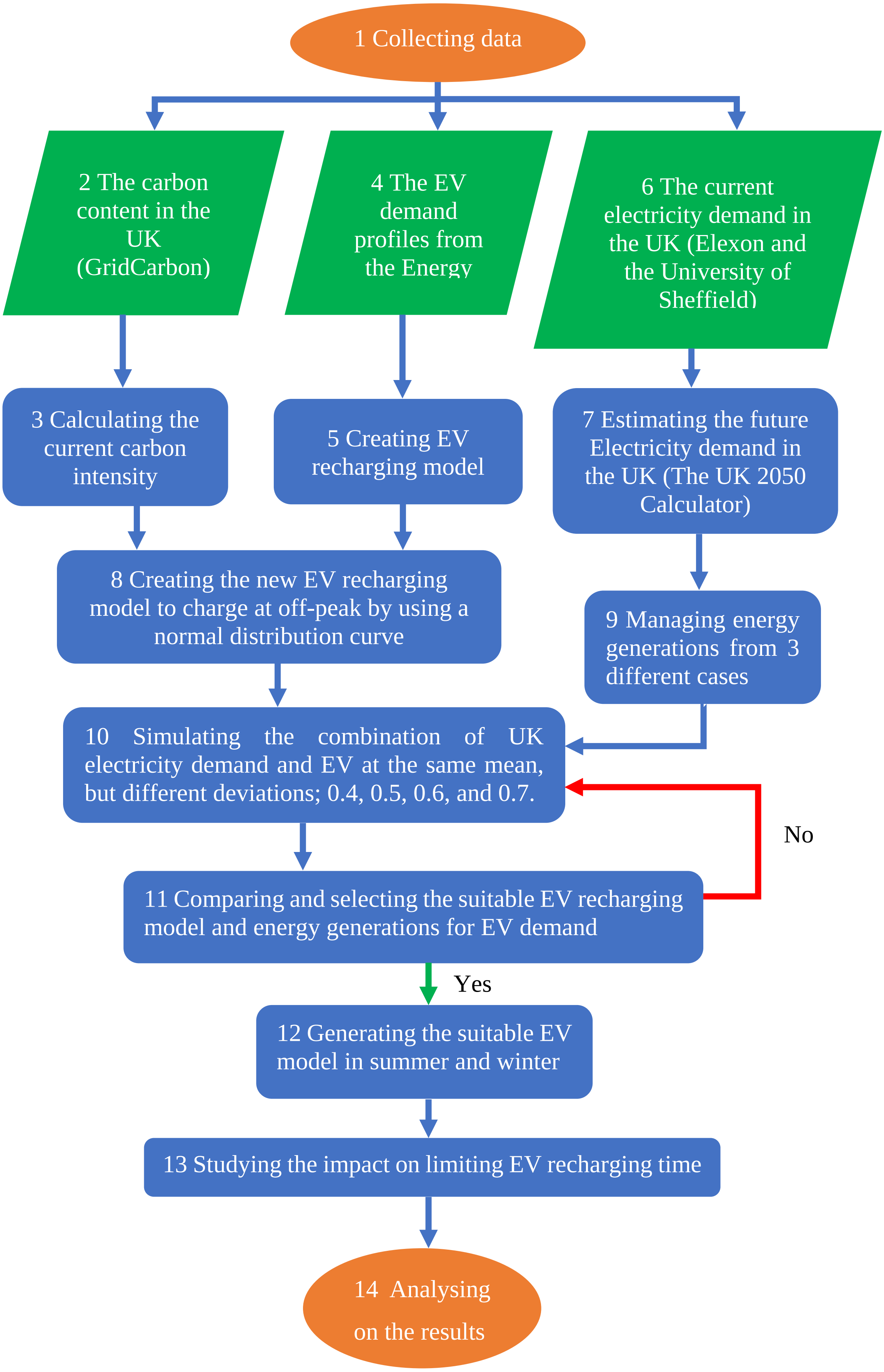
More specifically, it appears that the solar energy in winter could produce less power than summer. In contrast, wind energy had a larger proportion of the electricity generations during the winter.

Another difference in the electricity generation between winter and summer is that coal produced electric power at the high demand instead of an off-peak load.

Flowchart

To understand the methodology of the project, the flow chart shows the sequence to collect and analyse the data.

3.2 Flowchart of methodology



3.3 Carbon Intensity

Source	Carbon Intensity gCO_2/kWh Previous	Updated
Coal	910	937
Oil	610	935
Gas (Open Cycle)	480	651
Dutch Int.	550	474
Irish & East-West Int.	450	458
Gas (Closed Cycle)	360	394
Biomass	300	120
Other	300	300
French Int.	90	53
Hydro	0	0
Nuclear	0	0
Pumped Storage	0	0
Solar	0	0
Wind	0	0

Table 1 The carbon intensity of each electricity source in the UK (GridCarbon, 2017)

In table 1, each electricity generation has a different carbon intensity when it produces electrical power. According to Rogers A. and Parson O., they updated the latest carbon intensity from 2009 to 2017. Thus, the project will use the updated value of carbon intensity. Generally, the unit of carbon intensity is the weight of carbon dioxide emission (gram) per kilowatt-hour.

Table 1 shows that the generations that use fossil fuels had high carbon intensity such as coal, oil, and gas. Plus, the carbon intensity from fossil fuels increases slightly. The carbon content of coal accounts for 937 gCO_2/kWh which is the highest carbon emission. The second greatest number is followed by oil at 935. For the opened-cycle gas generation, the carbon intensity is considerably high at 651 gCO_2/kWh, while closed-cycle gas is likely to have less greenhouse gas emissions at the same amount of production. Surprisingly, new biomass produces carbon intensity less than the previous value and lower than a half of the generation from closed-cycle gas.

Likewise, the new version of interconnections that import electricity from Dutch and French reduce the carbon intensity from 550 to 474 and from 90 to 53, respectively. Meanwhile, the emission intensity from Irish and East-West interconnections rise a little from 450 to 458. For other generation, the number of emission intensity remains unchanged at 300 gCO_2/kWh.

Certainly, renewable sources like solar, hydro and wind power are environment-friendly. The zero-carbon emission also includes nuclear power and pump storage because both sources are assumed to produce power and release extremely low carbon dioxide emissions in their processes and cycles.

3.3.1 Carbon Intensity Calculation

According to the previous information by GridCarbon, each individual generation source has different weights of the carbon intensity. Thus, the carbon intensity can be estimated by using equations below:

$$CI_{gen} = \frac{\sum_{k=1}^{n}(g_k \times ci_k)}{\sum_{k=1}^{n} g_k} \quad (1)$$

Where:

CI_{gen} = The total carbon intensity from all generations (gCO_2/kWh)

$\sum_{k=1}^{n} g_k$ = The sum of electricity power from all sources (GWh)

ci_k = The carbon intensity of each generation (gCO_2/kWh)

However, when generators transfer power to substations or households, there are losses in the cables and wires. Hence, the carbon intensity of consumption is given by:

$$CI_{con} = \frac{CI_{gen}}{1-l} \quad (2)$$

Where:

CI_{con} = = The total carbon intensity of consumption (gCO_2/kWh)

CI_{gen} = The total carbon intensity from all generations (gCO_2/kWh)

l = losses in the distribution networks and the transmission lines (%)

The project assumes that the losses in the transmission network is 8 percent, which is based on GridCarbon, 2017. Thus, by using the equations above, the carbon intensity can be calculated from the statistic in Figure 1.

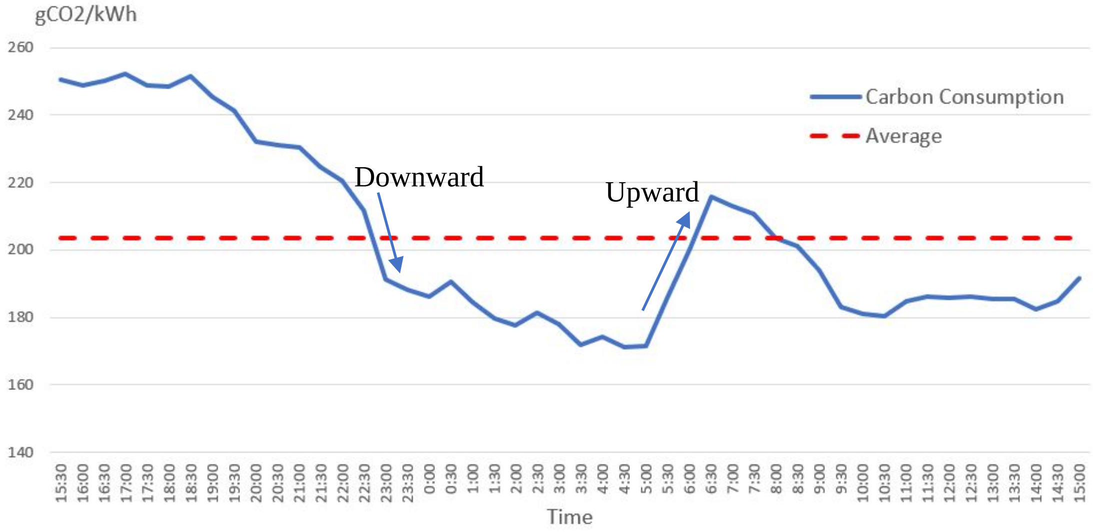


Figure 20 The intensity of carbon dioxide emission in the UK on a typical day (Elexon, 2018)

The line graph in Figure 20 which is converted from electricity generation profiles (Figure 1) illustrates the carbon intensity in the UK from 19th to 20th June 2018. The carbon intensity varied over the time frame, but a pattern of the line graph depended on types of the generations. A blue-bolded line was the carbon intensity in the UK, whereas a red-dashed line which is the average carbon intensity of these two typical days was approximately 204 gCO_2/kWh. Obviously, the carbon intensity dropped below the average value at around late night until early morning, then it rose nearly to 220 gCO_2/kWh at around 6:30 am. Then, the carbon intensity decreased again between the morning and mid-day. From afternoon to evening, an effect of the electricity demand and the types of supplies made the carbon intensity go up to the top at roughly 250 gCO_2/kWh by before it started to decline to the bottom at late night again.
Therefore, there are two periods that the carbon intensity is likely to remain at the low levels; during the night time and between around morning and mid-day.

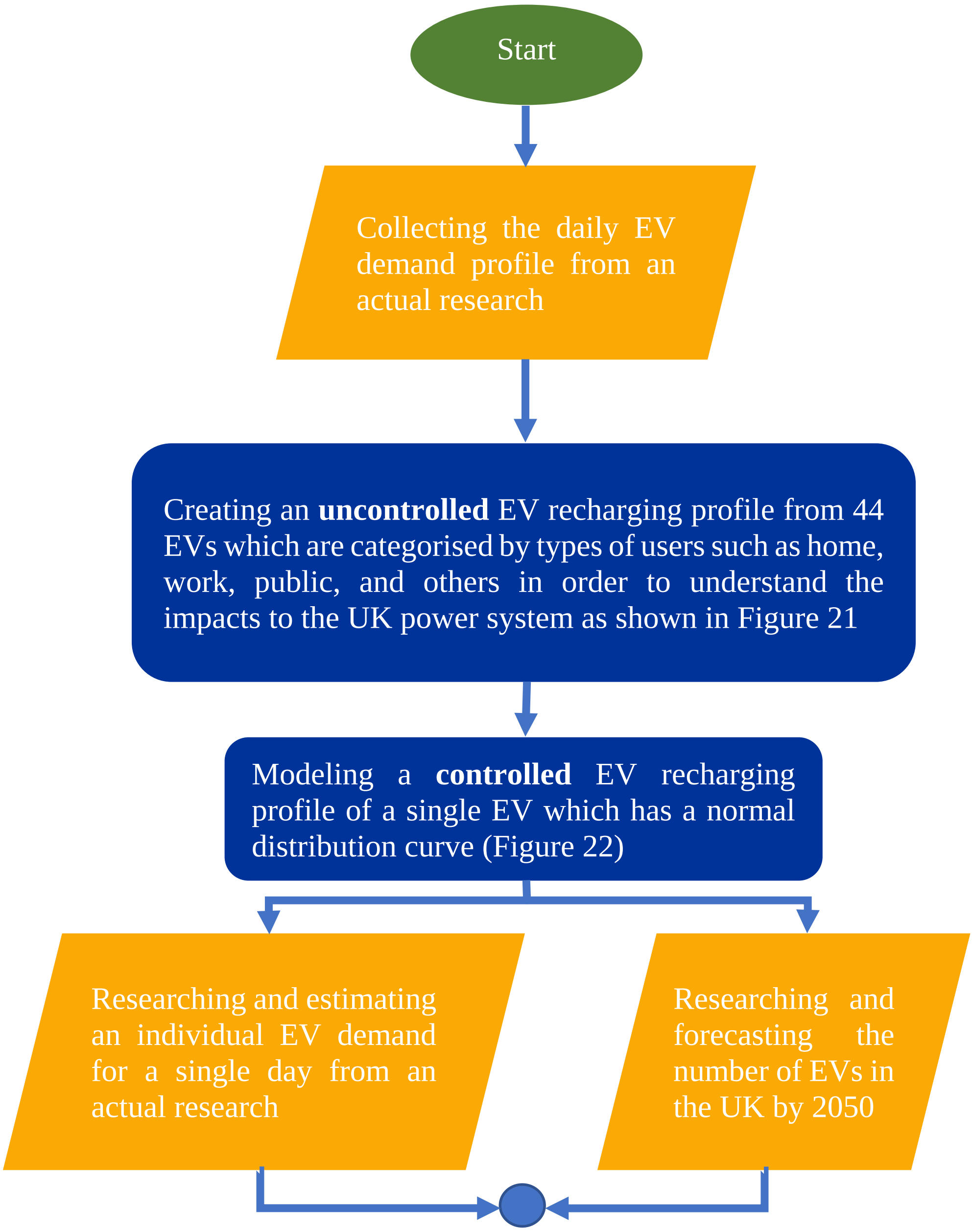
The project scopes to control EV recharging time during the night time because it occurs at the off-peak. Even though the carbon intensity from the morning to mid-day is considerably low, there is a high chance to overload the electrical power system in the future when it is added the future demand on EVs. Also, one reason that the carbon intensity is very low around mid-day because solar energy which is considered to have zero carbon intensity can produce a lot of electricity from the sunlight.

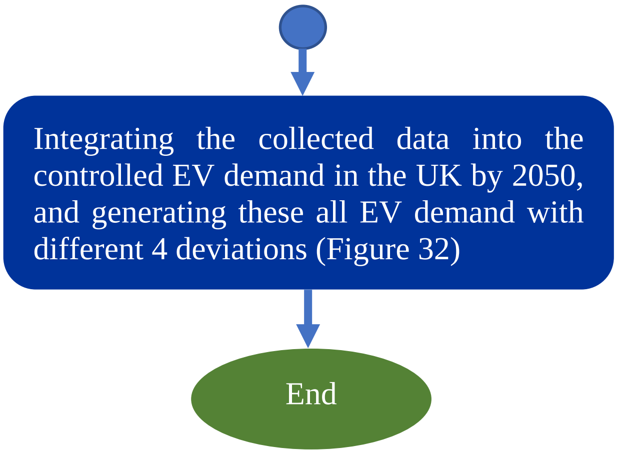
Analysing the off-peak period in Figure 20, the carbon intensity started to decline gradually from 6:30 pm until around 10:00 pm. After 10 pm, the carbon intensity dropped dramatically to the bottom at 5:00 am. Then the carbon intensity went up instantly between 5:00 am and 6:30 am in the morning. Thus, by considering this off-peak period, the project focuses to manage EV recharging time between the downward trend at 10:30 pm and the upward trend 6:00 am.

3.4 EV Recharging Profiles

Flowchart of creating the controlled EV demand profile

The steps of the methodology to collect and generate the EV recharging profiles are shown in the flowchart below;





First, the behaviour of drivers to recharge EVs is extremely necessary for optimising the local power grid to provide electricity and reducing the carbon content of generation sources. Hence, the project creates the current EV recharging profile in Figure 21.

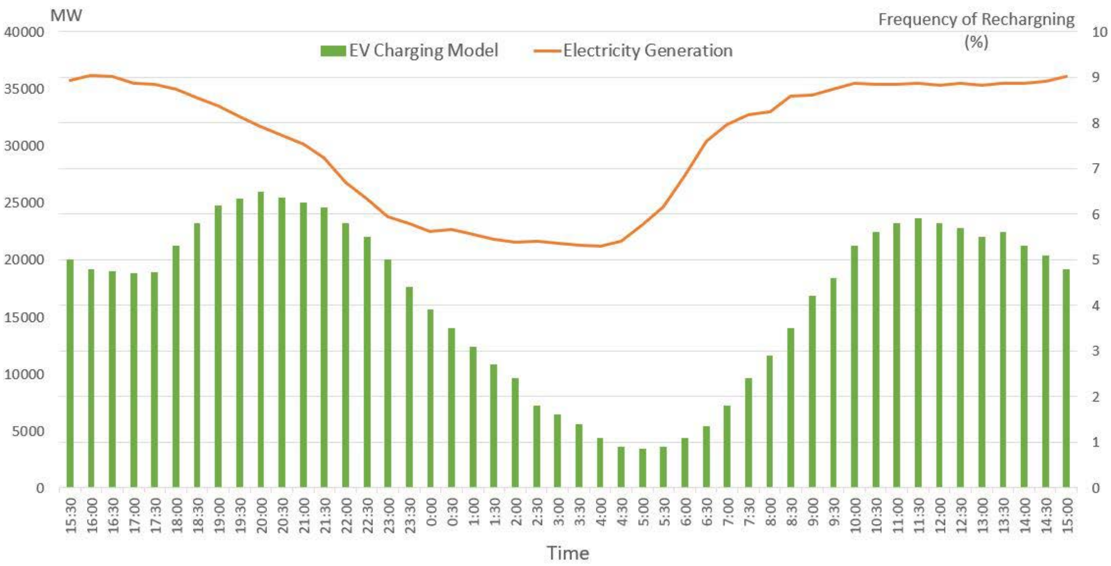


Figure 21 The EV demand profile and the total electricity generation in the UK on typical days

Figure 21 show EV demand profile in the bar chart and the total electricity generation in the line graph in the UK throughout the period. The EV charging model is the frequency of charging every 30 minutes which is created to predict and estimate the characteristic of the EV charging demand, based on the actual data from Energy Policy in 2013. According to Robinson et al., the project integrates the data of this scenario in Figure 8 that had the different types of users to establish the EV demand profile in Figure 21. The EV recharging model was weighted by the average number of recharging events which was 41.6 at home, 36.9 at work, 18.8 at public, and 12.4 at other (Figure 8). On the other hand, the total electricity generation is based on data from Elexon Portal and the University of Sheffield.

The EV charging demand sways over the period. However, it is clear that the EV charging demand has two peaks which are at mid-day and night. The EV demand goes down to the lowest demand at 5:00 am after reaching the highest point at 8:00 pm. After that, the EV demand grows to hit another peak at around noon.

After estimating the current EV demand profile, the project creates an ideal model of an individual EV recharging demand profile by using a normal distribution curve in order to reduce CO_2 emission (Figure 22). Also, Kang and Recker said that uncontrolled charging behaviour would cause to increase energy demand during peak time.

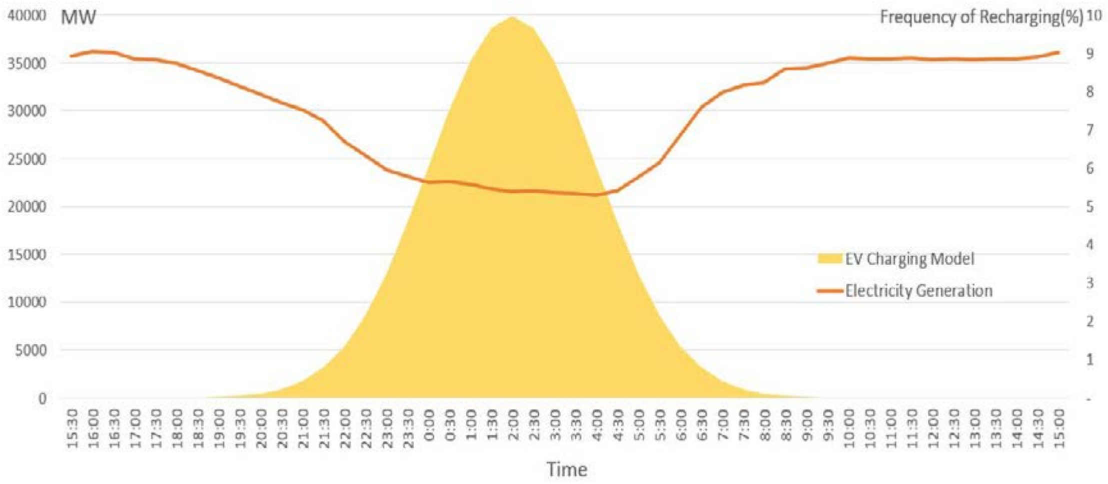


Figure 22 An ideal model of a single EV charging profile during the night time

The methodology of the project is to control the EV recharging time within a period from 18:30 h to 9:30 h as shown in a yellow area in Figure 22. The new recharging model has the normal distribution with the mean at 2:00 am because it is particularly designed to charge EV between late night and early morning. The frequency of recharging starts increasing gradually at the early evening, but after around 10.30 pm the demand rises remarkably in a few hours and reached the peak at 10 percent. Then the demand drops swiftly, and it slowly declines at around 6:30 am.

3.5 UK Electricity Demand in 2050

The project applies the UK 2050 Calculator to estimate the total energy consumption in the UK. The UK 2050 Calculator helps users to evaluate energy pathway in various options which are created by the Department of Energy and Climate Change in the UK (DECC) in order to meet the UK government's target to reduce at least 80% of carbon dioxide emission from the 1990 levels in 2050. The programme is able to estimate the total energy demand and supply and the total of greenhouse gas emissions. The total energy demand includes lighting and appliances, heating and cooling, industries, and transport, meanwhile energy supply consists of environmental heat, hydro, tidal, wind, nuclear, solar, bioenergy, gas, and oil. On the other side, the total greenhouse gas emission is divided into several sections such as aviation and shipping, agriculture, industrial process fuel combustion, bioenergy credit, and carbon capture.

In this project, a scenario of the National grid is used as a base case to get the total energy demand and supply in 2050. Moreover, the project will consider only the main parts of the energy demand and supply.

Transport

Due to EV future demand concern, two subjects involve in the National grid scenario, include the shift to zero emission transport and choice of zero emission technology. As it shown in Table 2, there are four different levels of the shifting to zero emission which is distinguished by types of vehicles. The National grid scenario selects 20 % of conventional cars (petrol or diesel), 32% of plug-in hybrid, and 48% of zero-emission cars which includes hydrogen fuel cell vehicles and BEVs. (level 3)

Types of vehicles	2007	2050			
		Level 1	Level 2	Level 3	Level 4
Convetional car	100%	77.5%	35%	20%	0
Plug-in Hybrid	0	20%	54%	32%	0
Zero emission car	0	2.50%	11%	48%	100%

Table 2 the estimation on types of vehicles in 2050

On the other side, the choice of zero-emission transport in the National grid is changed from 100% EVs and 0% hydrogen fuel cell vehicles (type A) to 80% EVs and 20 % hydrogen fuel cell vehicles (type B) in 2050.

Nuclear

UK Nuclear power plants generate heat at extremely the high temperature and convert less than 50% of this energy to electricity to the grid. For instance, 164 TWh/year of heat at was UK nuclear power plants in 2007 changed to 63 TWh/year of electricity (Department for Business, Energy & Industrial Strategy, 2013). In Figure 23, there are 4 trends of the nuclear power generations; no new nuclear power plants are established, a 4-fold, a 9-fold, and a 13-fold increase in capacity from 2010 levels until 2050. Besides, Figure 23 also compares the UK nuclear generations with the EU, USA, and France. Based on the National grid, nuclear power stations in 2050 is expected to be able to produce nearly 39 GW or 275 TWh/year, plus new nuclear power stations as demonstrated in Figure 23. (level 1.7)

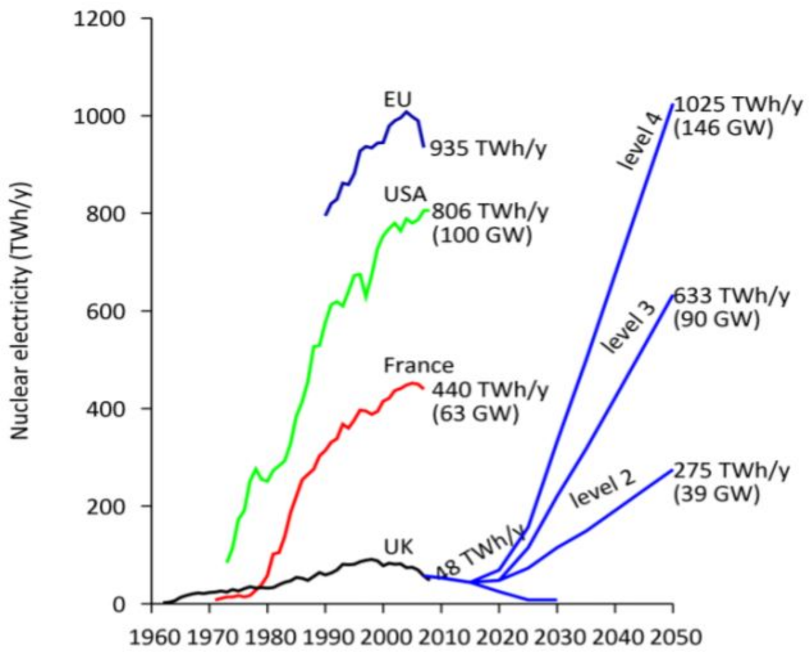


Figure 23 The trends of nuclear energy production in 2050 (Department for Business, Energy & Industrial Strategy, 2013)

Wind

Wind energy generations are categorised into two types; offshore and onshore wind. Similar to nuclear power, both wind energies have 4 levels for the future generation. The higher level means the larger energy supply to customers in the future as illustrated in Figure 24 and Figure 25. Both offshore and onshore wind energy also compare the trend lines with the EU, Germany, Spain, and the world.

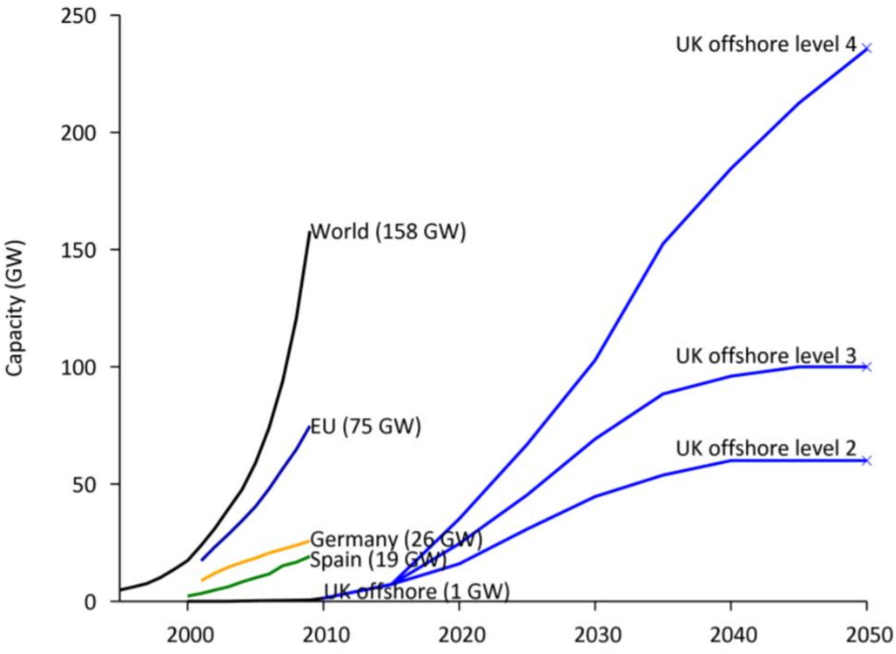


Figure 24 The comparison on trends of offshore wind power in the UK between 2000 and 2050 (Department for Business, Energy & Industrial Strategy, 2013)

All types of offshore wind turbines in the UK were fixed to the ground under the seawater (Department for Business, Energy and Industrial Strategy, 2013). For the National grid scenario, the electricity supply from offshore wind is assumed to nearly reach 60 GW or about 237 TWh/year in 2050. (level 1.6)

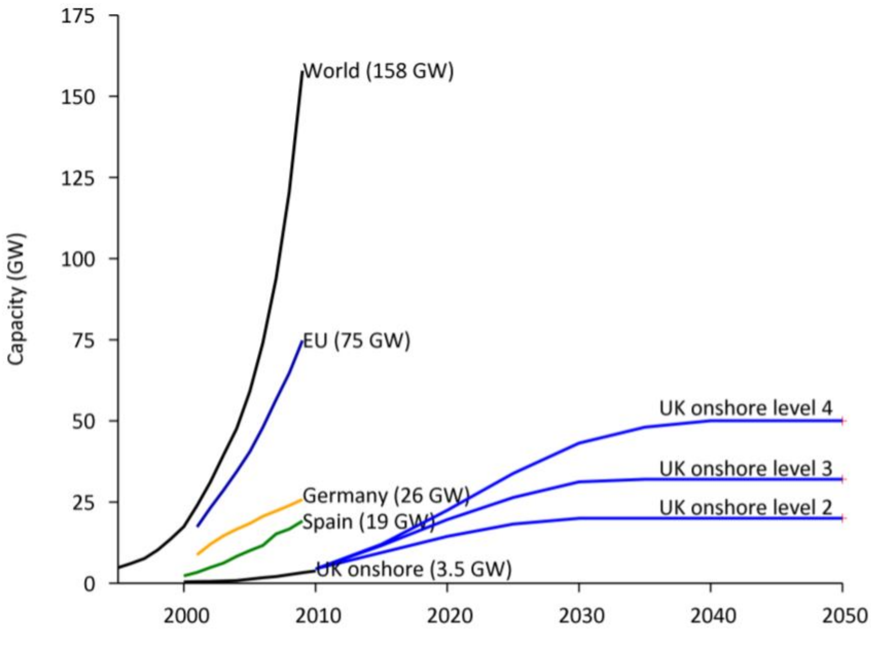


Figure 25 The comparison on trends of onshore wind power in the UK between 2000 and 2050 (Department for Business, Energy & Industrial Strategy, 2013)

On the other hand, this scenario assumes that onshore wind energy will generate power at around 10 GW in 2020 and continue increasing gradually until achieving 20 GW or 53 TWh/year in 2030. From 2030 to 2050, the supply remains steady at that level because of replacement on retired turbines. (level 2)

Solar

The scenario predicts that the capacity of UK solar energy in 2050 will maintain at 1 TWh for generating electricity (level 1.2), but 30% more solar panels will be installed for hot water. (level 2)

Biomass

For biomass, the scenario expects the UK to expand the capacity of biomass plants in order to achieve 600 MW or 4.7 TWh/year in 2010 and remain stable at that state until 2050. (level 1)

Hydro

By renovating existing hydro schemes, hydroelectric power stations are assumed to increase to 2.1 GW or about 7 TWh/year by 2050. (level 2)

Tidal Stream

Tidal stream technologies generate electric power by using the tides underwater to spin turbines. By 2050, tidal stream capacity is presumed to grow to 1.9 GW or 6 TWh/year of electricity. (level 2)

Other developments

There will be many improvements on technologies and capacities of the energy supply in the UK such as insulation, district heating, energy management on residential and commercial demand, Carbon Capture and Storage (CCS) power station, and Geosequestration.

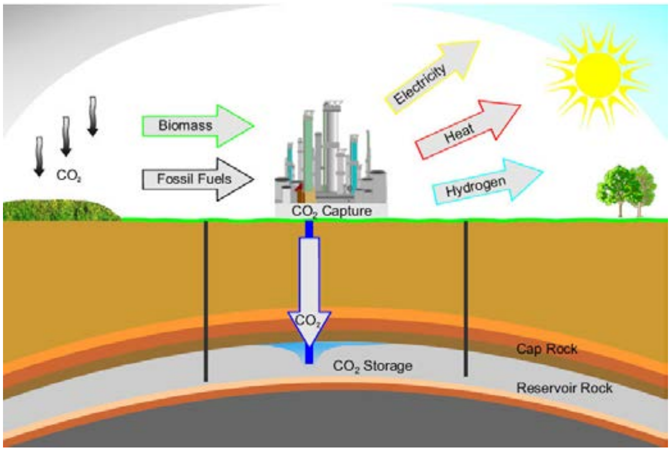


Figure 26 Carbon Capture and Storage (Hughes N., 2017)

Figure 26 shows the process of Carbon Capture and Storage. This technology captures CO_2 from a power plant in the combustion process and stores it in deep underground constructions.

While Figure 27 presents a carbon sequestration machine which helps to filter CO_2 emission directly from the air and store it underground by using geochemical system.

Figure 27 A carbon sequestration machine

Thus, the UK energy demand in 2050 is 1,467 TWh/year or 167.12 GW/day in Figure 28. Meanwhile, the project assumes that the current energy demand is close to the demand in 2020 which is 1709 TWh/year or 195.10 GW/day. As a result, the energy consumption is anticipated to decline by around **14.34 %** from 2020 to 2050. The percentage of energy reduction is used to find the total energy consumption in 2050 by subtracting the energy sources of the current electricity demand profiles in **Figure 1**.

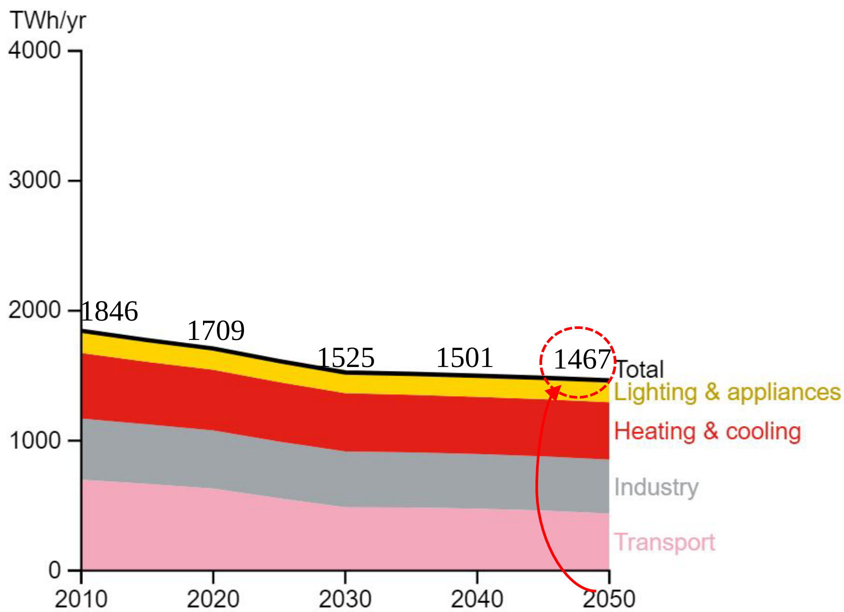


Figure 28 The total energy consumption in the UK from 2010 to 2050

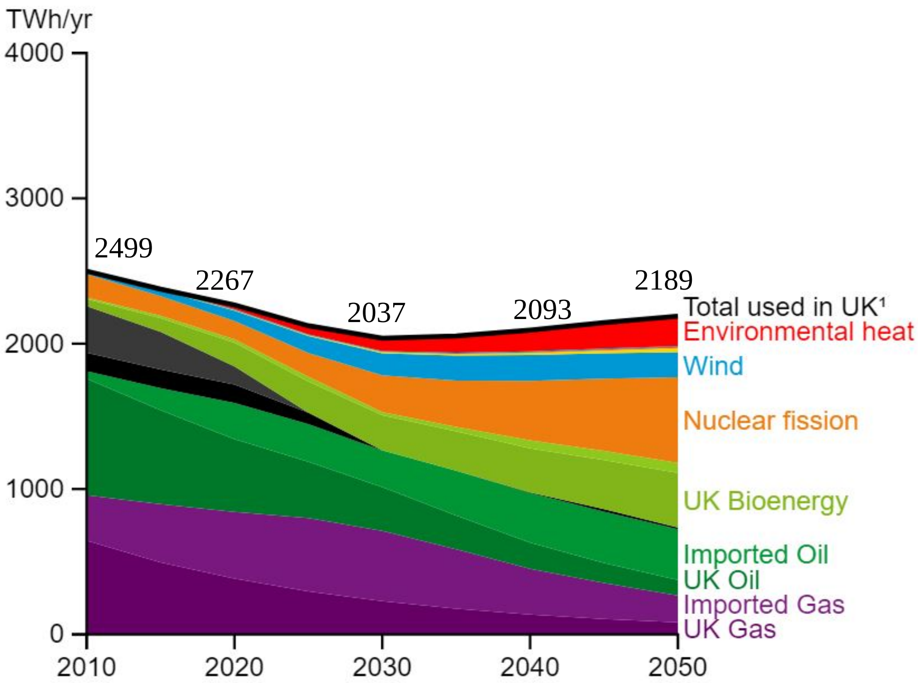


Figure 29 The total energy supply in the UK from 2010 to 2050

On the other hand, it is clear that the capacity of energy supply begins to decline from around 2,500 TWh/year in 2010 to 2,037 TWh/year in 2030. In the next two following decades, the energy supply expects to grow and reach 2,189 TWh/year in 2050 as shown in Figure 29. The prediction on the total energy supply in the UK helps to estimate the maximum capacity of each energy source.

3.6 EV Charging Demand in 2050

The project assumes that the average of an individual EV which travels about 17.5 kilometres in distance consumes approximately **3.5 kWh per day** (Aunedi M et al., 2014). Then, the number of EVs in 2050 can be predicted by Element Energy.
According to Element Energy, the roadmap for transportation in the UK are modelled by two scenarios, the Committee on Climate Change (CCC) targets and Moderate ambition.

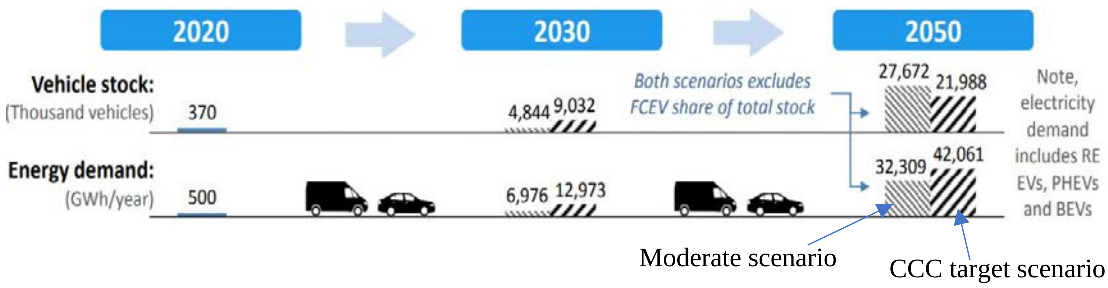


Figure 30 The estimation on the number of vehicles and the amount of energy demand in 2020, 2030 and 2050 (Element Energy, 2015)

Figure 30 demonstrates the future demand on EVs in the year 2020, 2030, and 2050. Also, both CCC target scenario and Moderate scenario anticipate that there will be an increasing demand on EVs. However, EVs in both scenarios does not include Fuel Cell Electric Vehicle (FCEV).

In 2020, the number of EVs is expected to remain around 370 thousand vehicles with energy demand at 500 GWh/year. After a decade, the EV demand will go up rapidly and reach 4,844 thousand vehicles (6,976 GWh/year) for the Moderate scenario, while CCC target scenario estimates that the EV demand will rise even higher than the Moderate scenario to 9,032 thousand vehicles (12,973 GWh/year).

By 2050, the EV demand is expected to increase significantly for both cases. For the Moderate scenario, EVs account for **27,672,000** vehicles, and the amount of energy demand may be up to 32,309 GWh/year. On the other side, the CCC target scenario predicts that the number of EVs will be around **22,000,000** vehicles, but the energy demand will be over 40,000 GWh/year in 2050.

The project considers the Moderate scenario for the number of EVs in the future because it has the proportion of BEV and PEV combined as same as the shift to zero emission transport in the total energy demand of the UK 2050 Calculator. In addition, the Moderate scenario has the larger number of EVs than the CCC target which helps to understand the impact of higher demand.

Thus,

The total EV demand in 2050 = The number of EVs in 2050 x an individual EV demand

= 27,672,000 x 3.5

= 96,852,000 kWh/day or **96.852 GWh/day**

By the future demand from EVs in 2050, the project plots a graph of uncontrolled EV demand and the UK total demand in 2050 in order to understand the impact that may occur as presented in Figure 31.

Uncontrol EV demand

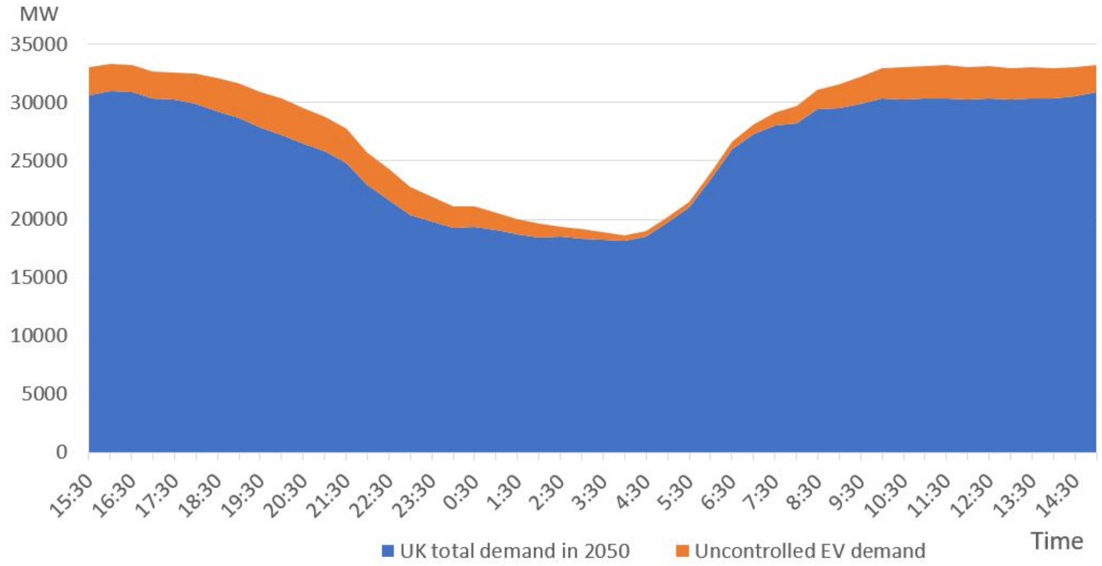


Figure 31 The UK total demand in 2050, added the uncontrolled EV demand

After mixing the uncontrolled EV demand in Figure 31, it is clear that the future EV demand not only increases loads to the electrical system at on-peak hours but it may also boost carbon dioxide emission. For example, the EV demand at 3:30 pm accounts for almost 10 percent of the total energy demand in the UK.

Control EV demand

According to the controlled model in Figure 22, the controlled EV demand in 2050 is distributed throughout two typical days (Figure 32).

In order to find the suitable EV recharging model, the project has made four different deviations include 0.4, 0.5, 0.6, and 0.7.

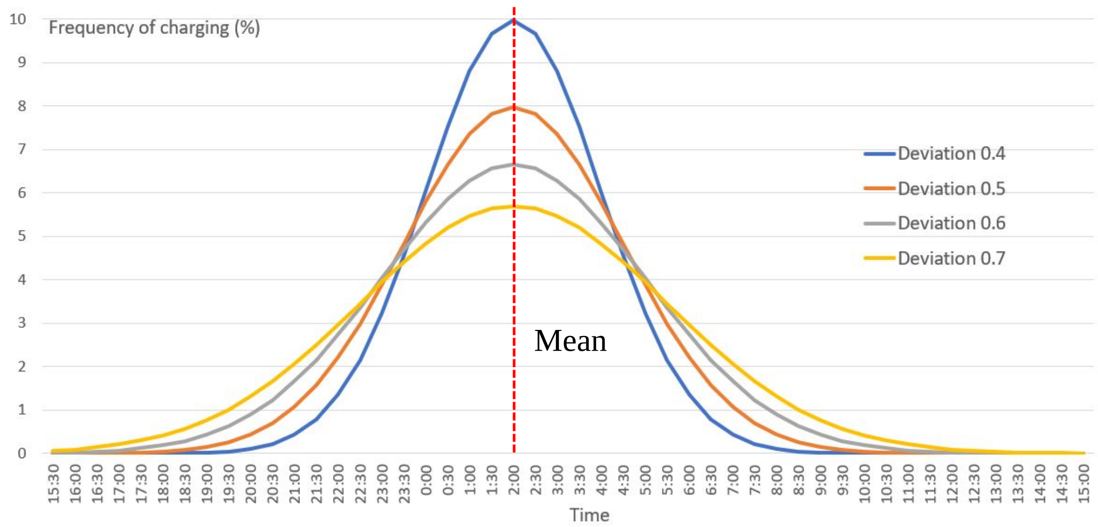


Figure 32 The frequency of EV recharging demand in 4 different deviations

The demand of four EV recharging profiles is a normal distribution, and all models have the same mean at 2:00 am as shown in Figure 32. In detail, each model has different deviations from 0.4 to 0.7. Clearly, the highest frequency of charging which accounts for 10 percent is the EV recharging demand with deviation at 0.4, followed by 0.5, 0.6, and 0.7 respectively. In contrast, the EV demand of deviation 0.7 is the widest distribution.

According to the total EV demand, the project estimates and generates the controlled and uncontrolled EV demand on typical days in the UK by 2050 (Table 3)

Time	EV demand in 2050 (kW)				
	Uncontrolled EV	Controlled EV deviation	Controlled EV deviation	Controlled EV deviation 0.6	Controlled EV deviation
15:30	2,421.30	0.01	1.14	14.09	61.32
16:00	2,324.45	0.04	2.59	24.90	93.17
16:30	2,300.24	0.12	5.66	42.79	138.71
17:00	2,276.02	0.39	11.85	71.54	202.34
17:30	2,285.71	1.16	23.87	116.32	289.20
18:00	2,566.58	3.24	46.18	183.95	404.98
18:30	2,808.71	8.54	85.85	282.94	555.67
19:00	3,002.41	21.13	153.33	423.27	747.02
19:30	3,075.05	49.13	263.11	615.86	983.98
20:00	3,147.69	107.31	433.79	871.52	1,269.91
20:30	3,084.74	220.18	687.16	1,199.53	1,605.83
21:00	3,026.63	424.41	1,045.83	1,605.76	1,989.59
21:30	2,978.20	768.51	1,529.30	2,090.67	2,415.25
22:00	2,808.71	1,307.28	2,148.58	2,647.45	2,872.76
22:30	2,663.43	2,089.03	2,900.28	3,260.66	3,347.91
23:00	2,421.30	3,136.01	3,761.46	3,905.89	3,822.82
23:30	2,130.74	4,422.48	4,687.07	4,550.62	4,276.92
0:00	1,888.61	5,858.84	5,611.44	5,156.53	4,688.30
0:30	1,694.91	7,291.44	6,454.69	5,683.04	5,035.43
1:00	1,501.21	8,524.56	7,133.54	6,091.72	5,299.00
1:30	1,312.34	9,362.40	7,574.65	6,350.90	5,463.73
2:00	1,162.22	9,659.59	7,727.67	6,439.73	5,519.77
2:30	871.67	9,362.40	7,574.65	6,350.90	5,463.73
3:00	774.82	8,524.56	7,133.54	6,091.72	5,299.00
3:30	677.96	7,291.44	6,454.69	5,683.04	5,035.43
4:00	532.69	5,858.84	5,611.44	5,156.53	4,688.30
4:30	435.83	4,422.48	4,687.07	4,550.62	4,276.92
5:00	411.62	3,136.01	3,761.46	3,905.89	3,822.82
5:30	435.83	2,089.03	2,900.28	3,260.66	3,347.91
6:00	532.69	1,307.28	2,148.58	2,647.45	2,872.76
6:30	653.75	768.51	1,529.30	2,090.67	2,415.25
7:00	871.67	424.41	1,045.83	1,605.76	1,989.59
7:30	1,162.22	220.18	687.16	1,199.53	1,605.83
8:00	1,404.35	107.31	433.79	871.52	1,269.91
8:30	1,694.91	49.13	263.11	615.86	983.98
9:00	2,033.89	21.13	153.33	423.27	747.02
9:30	2,227.60	8.54	85.85	282.94	555.67
10:00	2,566.58	3.24	46.18	183.95	404.98
10:30	2,711.86	1.16	23.87	116.32	289.20
11:00	2,808.71	0.39	11.85	71.54	202.34
11:30	2,857.13	0.12	5.66	42.79	138.71
12:00	2,808.71	0.04	2.59	24.90	93.17
12:30	2,760.28	0.01	1.14	14.09	61.32
13:00	2,663.43	0.00	0.48	7.75	39.54
13:30	2,711.86	0.00	0.20	4.15	24.98
14:00	2,566.58	0.00	0.08	2.16	15.46
14:30	2,469.73	0.00	0.03	1.09	9.38
15:00	2,324.45	0.00	0.01	0.54	5.57

Table 3 The estimation of the uncontrolled and controlled EV demand with deviations from 0.4 to 0.7

3.7 Energy Supply Management

Before integrating the controlled EV demand in different deviations, the project has managed the power supplies to serve the EV demand by separating into 3 cases; only gas generation, gas generation with wind energy and nuclear power, and gas generation with nuclear power, all renewables in the UK, and biomass.

The main idea of managing power generations is to use gas generation as a main source to supply EV demand because gas generation is the biggest source in the UK and it is also be able produce electricity rapidly.

The next step is to share to EV demand from the gas generation to other energy sources that the capacity of each source in 2050 are fixed as much as in the present. Whereas the other sources are assumed to supply less electricity by 14.34%.

Nevertheless, these three cases do not prioritise the sequence of energy sources to supply electricity.

For example,

Case 1

Time	Combined	Nuclear	Wind
15:30	18592	5424	1625
16:00	18593	5429	1602
16:30	18604	5439	1616

Table 4 Gas generation supplies EV demand in 2050

Case 2

Time	Combined	Nuclear	Wind
15:30	17412	6332	1897
16:00	17416	6338	1870
16:30	17423	6349	1886

Table 5 Gas, Nuclear and Wind generation supplies EV demand in 2050

Table 3 (left) and Table 4 (right) show the estimation on the amount of electricity from combined cycle gas turbines, nuclear, and wind generations within an hour in 2050. In case 1, only the gas generation serves EV demand, while nuclear and wind power energy is reduced by 14.34% in 2050. The case 2 uses the combination of gas, nuclear and wind power to serve EV demand. By sharing EV demand to nuclear and wind generation, electricity at 15:30 h is forced to increase from 5,424 MW (85.66%) to the same amount in the present value at 6,332 MW (100%) for nuclear and similarly for wind from 1,625 MW to 1,897 MW. As a result, it is not only the gas generation produces less electric power, but it also decreases CO_2 emission from fossil fuels

Similarly, the case 3 also uses the strategy to share EV demand from gas to other sources. These sharing demands include all renewables, nuclear power, and bioenergy. Figure 33 presents the carbon intensity of 3 different cases that supply the EV demand in the UK by 2050. These line graphs are plotted by using the current data in Figure 20 to predict the carbon intensity of each case.

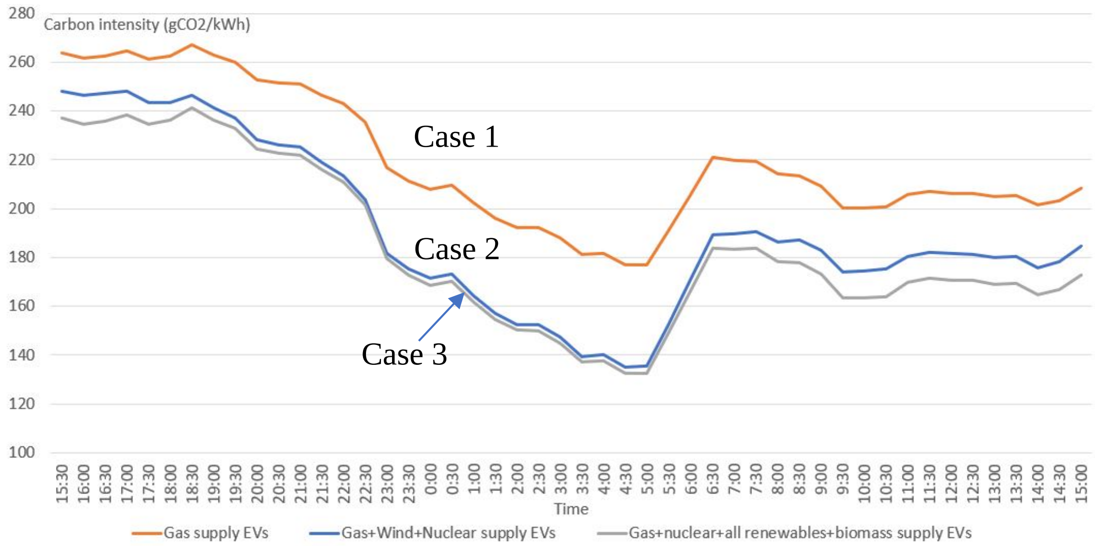


Figure 33 The carbon intensity of the different generations to supply EV demand within 24 hours

Overall, it is clear that the carbon intensity in case 1 is higher than the other cases throughout the period. For case 2 and 3, the carbon intensity is nearly the same value at night. But the gap of carbon intensity between case 2 and case 3 is getting bigger during the daylight.

Gen. supply EV demand	Total carbon intensity(gCO2/kWh)
Case 1: Gas	10,523
Case 2: Gas + Wind + Nuclear	9,141
Case 3: Gas + All renewables + Nuclear +Biomass	8,828

Table 6 The total carbon intensity of 3 cases, separated by generations supply EV demand within 24 hours

Table 5 shows the number of total carbon intensity in case 1, 2, and 3 on a typical day in summer. In Table 5, the carbon intensity in case 2 decreases more than 10 percent of the case 1 by sharing EV demand to wind energy and nuclear power. Moreover, if all renewable energy, nuclear power, and bioenergy help gas generations to supply electricity, the carbon emission drops almost 20 percent from 10,523 to 8,823 gCO_2/kWh.

Then, the project will apply **case 3** which is the lowest carbon intensity with the controlled EV models at different deviations as presented from Figure 34 to 37.

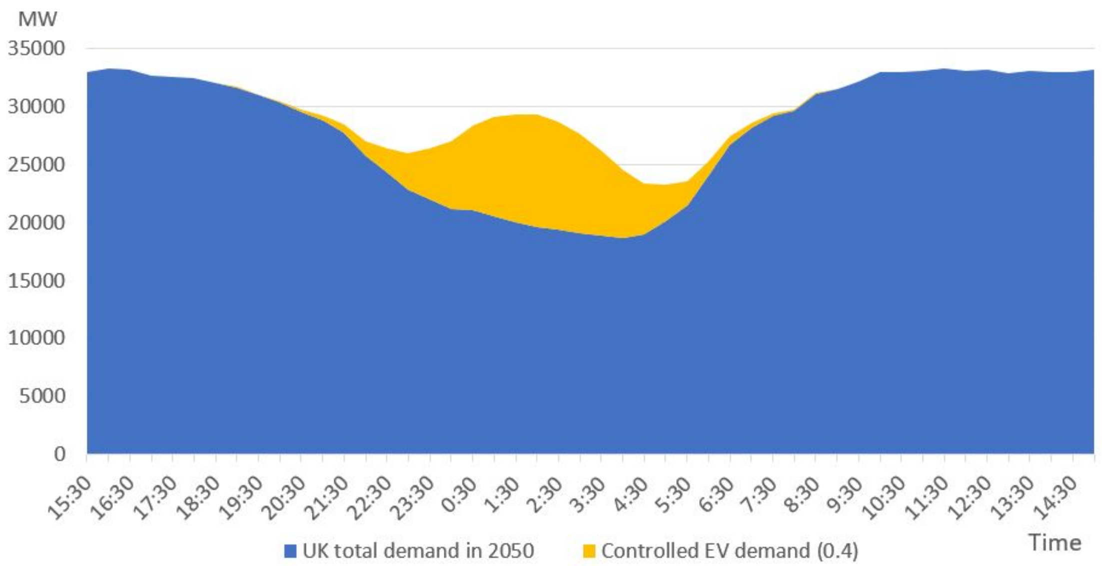


Figure 34 The UK electricity demand in 2050 and the controlled EV demand at deviation **0.4**

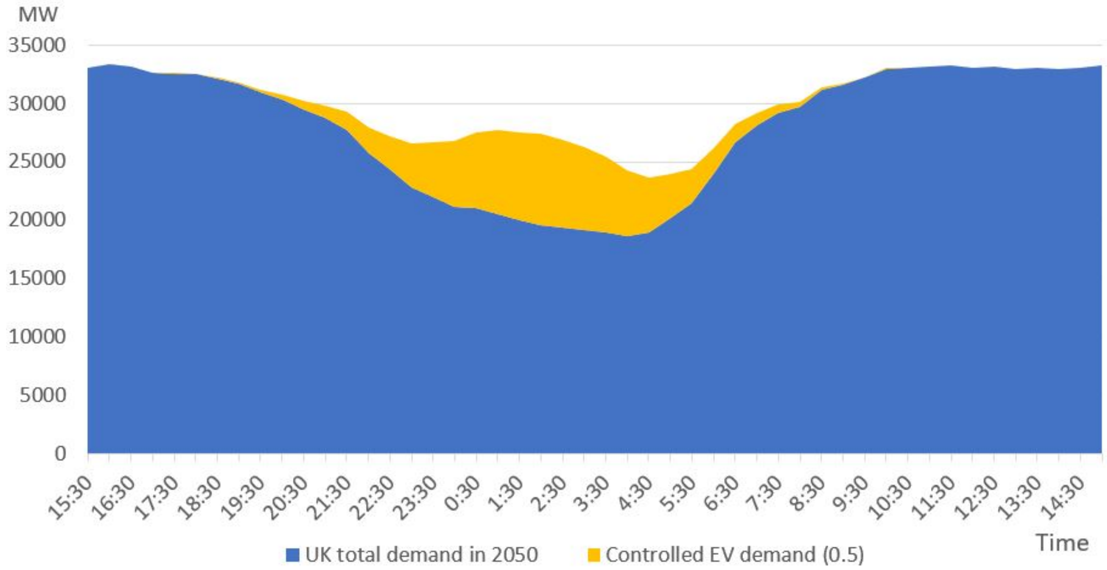


Figure 35 The UK electricity demand in 2050 and the controlled EV demand at deviation **0.5**

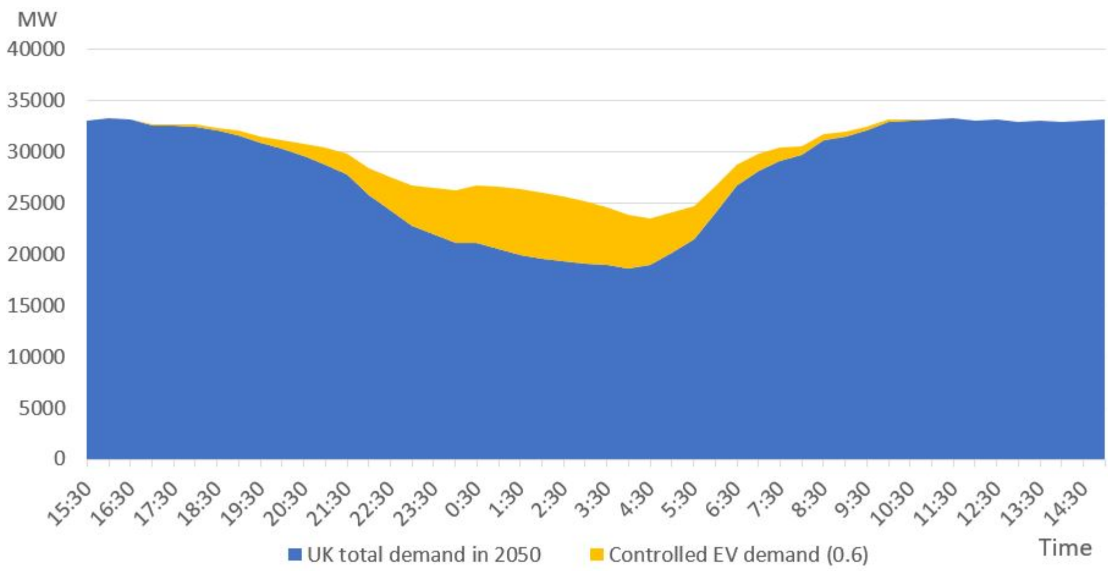


Figure 36 The UK electricity demand in 2050 and the controlled EV demand at deviation **0.6**

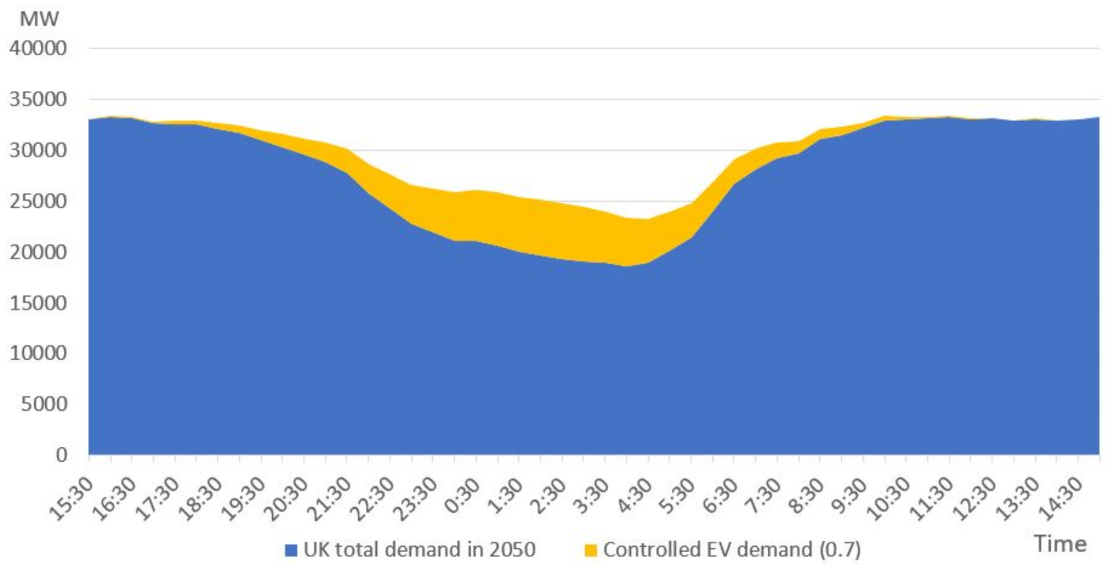


Figure 37 The UK electricity demand in 2050 and the controlled EV demand at deviation **0.7**

From Figure 34 to 37, the graphs illustrate the electricity demand with the controlled EV demand on typical days in summer, 2050. In Figure 34, the EV demand model with deviation at 0.4 makes another peak demand which almost reaches 30,000 MW between 1:30 am and 2:30 am. This means deviation 0.4 may affect the electrical system by increasing loads to generations at night. While, the more deviation on EV demand is the greater energy distribution to the system will have as it presented in Figure 35, 36, and 37.

4 Result

In this part, the project will show the result of integrating the EV models with the UK electricity demand in summer and winter to understand the impact of shifting the EV demand.

Analysing a gas generation from an increasing EV demand

To analyse the effect of an overshooting during the night time, the project focuses on the energy demand between 11:30 pm and 3:30 am.

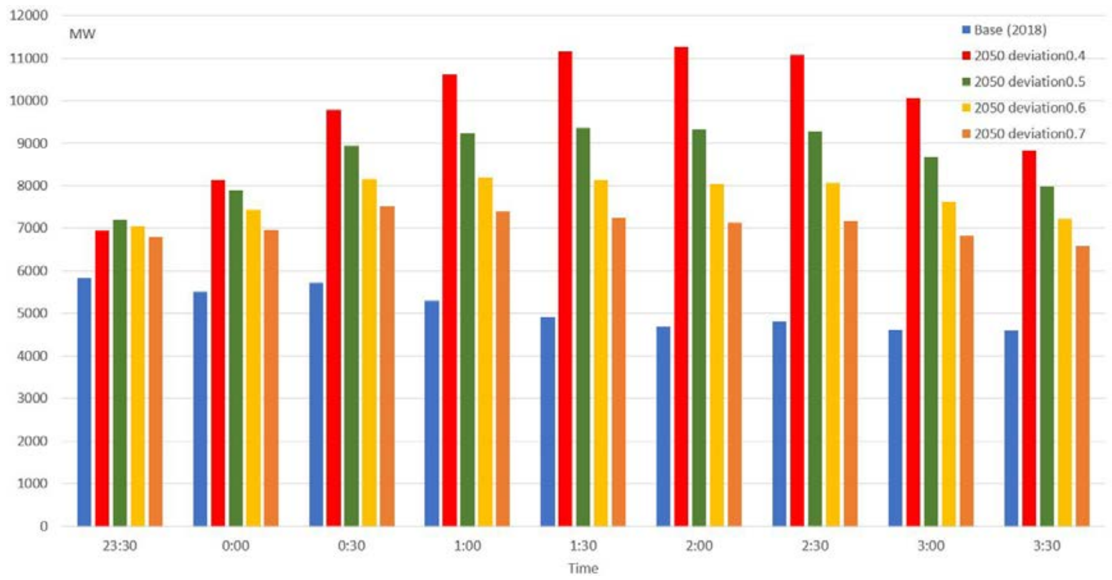


Figure 38 The UK electricity demand from gas in 2018 without EVs and 2050 with EV demand at different deviations

The bar chart in Figure 38 compares the electricity demand which is generated by gas in 2018 (without EV demand) and 2050 with EV models at deviation 0.4, 0.5, 0.6, and 0.7.

Overall, the UK electricity demand from the gas generation which is mixed with EV models at deviation 0.4 is higher than the others, whereas the 2018 energy demand is the lowest.

In 2018, the electricity demand decreased slightly every 30 minutes over the time frame. For the EV estimation in 2050, the demand of deviation 0.5, 0.6, and 0.7 rises little by little from 11:30 pm to 12:30 am, then it remains stable until 2:30 am. In the last hour, the demand starts declining gradually. On the contrary, the 2050 energy demand at deviation 0.7 has a similar pattern to other deviations in 2050, but it goes up and down significantly.

Interestingly, by comparing the electricity generation by gas between 2018 and 2050 which is added the EV model at deviation 0.7, the energy generation rises more than double from 1:00 am to 3:00 am. The result of the increasing energy demand may lead to burden the gas generation during the night time. Besides, the gas generation will rise more carbon dioxide emissions to the atmosphere.

Moreover, the smallest gap in electricity generation that is around 1,500-2,000 MW (between 20 and 30 percent) is between 2018 and the EV model at deviation 0.7.

Hence, there is a higher possibility that the EV model at deviation 0.4 will overload the UK electrical power supply because of a lot of the high EV demand within a short of periods. Unlike, deviation 0.7 is likely to have the lowest chance to affect the electrical system.

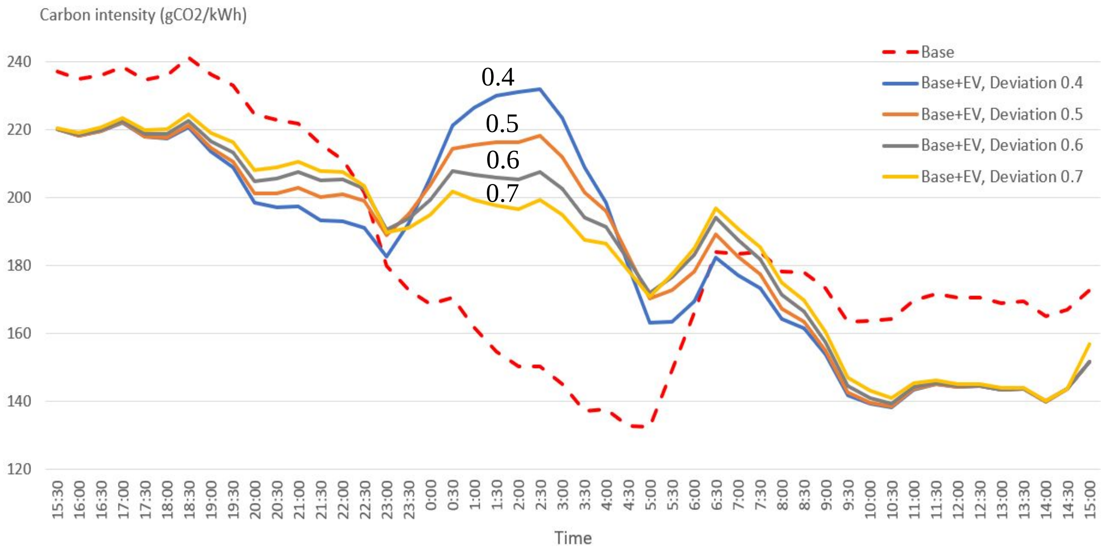


Figure 39 Comparing the carbon intensity of UK electricity demand plus EV model at four different deviation, include **0.4, 0.5, 0.6, and 0.7** in a **summer** period, 2050

As it can be seen in Figure 39, the line graphs compare the carbon intensity in the UK on typical days in 2050. The four-line graphs have different deviations of EV demand profiles from 0.4 to 0.7, exclude the baseline which is the future electricity demand.

After combining EV recharging demand profile in different deviations with the future electricity demand in the UK, the energy demands are slightly changed.

Clearly, EV with deviation 0.4 which has the lowest distribution of EV recharging demand and the greatest frequency of recharging releases the highest carbon intensity. The deviation 0.4 exceeds 230 gCO_2/kWh at around 3:00 am.

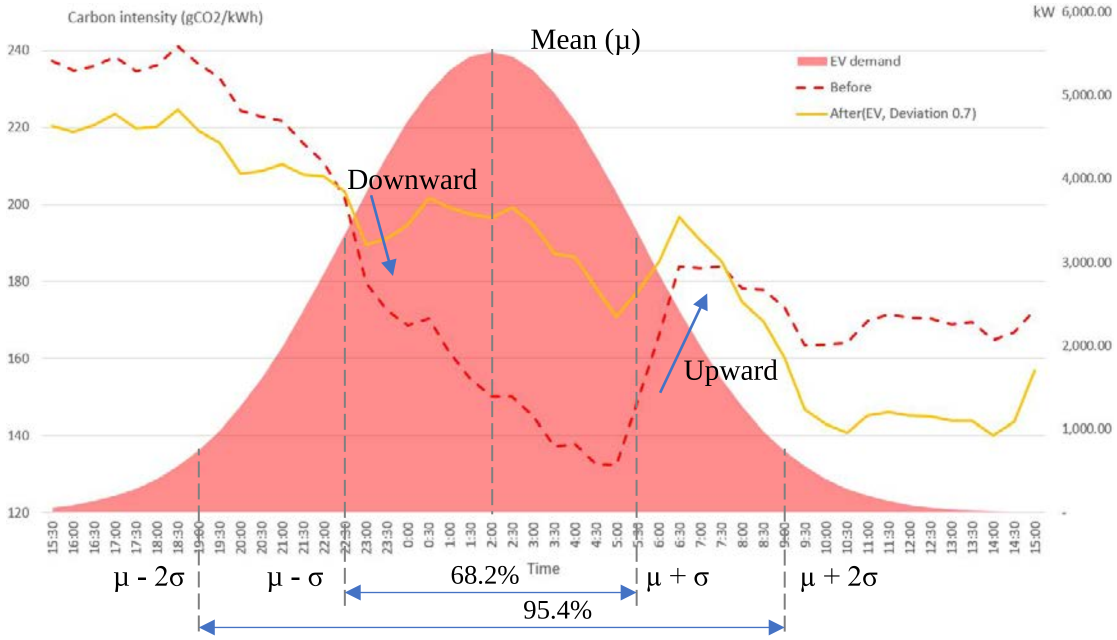


Figure 40 the comparison between the carbon intensity of electricity demand in the UK before and after controlling EV demand

The line graph in Figure 40 compares the carbon intensity of UK electricity demand before and after changing EV recharging demand to the normal distribution with mean at 2:00 am and the deviation at 0.7. The greatest EV demand is about 5.5 MW. It seems that a majority of the high EV demand (pink area) is between 10:30 pm and 5:30 am. The lower demand is spread down on both sides of the EV model at before 10:30 pm and after 5:30 am. As a result of the intensive demand at the off-peak, the carbon intensity after adding EV demand (yellow line) exceeds the previous values (red-dashed line). Apart from the off-peak, the yellow line remains below the red-dash line.

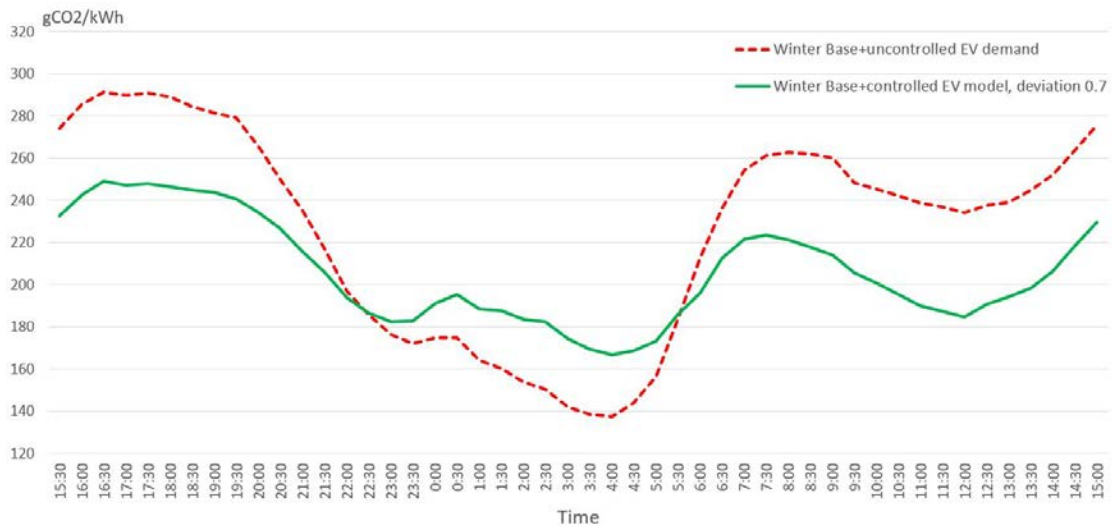


Figure 41 The carbon intensity of UK electricity demand with and without EV model at deviation **0.7** in **winter**, 2050

Figure 41 represents two-line graphs which are the carbon intensity of UK electricity demand with and without controlled EV model on typical days by 2050. It seems that the carbon intensity before adding the controlled EV demand fluctuates notably between around 140 and 300 gCO_2/kWh throughout the period. After using the controlled EV demand, the carbon intensity becomes more stable and varies between 160 and 250 gCO_2/kWh as it shown in Figure 41.

Season	Model	Carbon Intensity (gCO2/kWh)	
		Average	Total
Summer	Uncontrolled EV	219.24	10523
	Controlled EV at deviation 0.7	185.32	8895
Winter	Uncontrolled EV	226.10	10853
	Controlled EV at deviation 0.7	206.17	9896

Table 7 The average and total UK carbon intensity in summer and winter, 2050

The average and total UK carbon intensity of the controlled and uncontrolled EV demand profiles on typical days in summer and winter is presented in Table 6. By comparing the same models in different seasons, winter has the higher average and total carbon intensity. Besides, the uncontrolled EV demand releases more CO_2 emissions for both seasons.

Apparently, changing from uncontrolled to controlled EV demand reduces greenhouse gas emissions by over 1,500 gCO_2/kWh per day in summer, while about 1,000 gCO_2/kWh per day of carbon emission reduction is decreased in winter.

4.1 Effects on controlling EV demand in the Future

Controlling EV demand to mostly recharge at night time may cause problems to users in the future such as

- Drivers may confront a difficulty to charge EV, especially at workplace and commercial during a peak load because in these two cases some people may have to drive for a long distance.
- The power system may be unreliable because the main source of energy is changed from gas to wind energy which an amount of energy varies by wind speed.
- For an emergency case, an EV requires to recharge the battery during peak loads while traveling at a remote area.
- It is inevitable for some drivers who work on shift work to charge EVs at anytime and anywhere because the shift schedules may be changed every week or month.
- It may affect a lot of companies which makes EV charging points because most people will tend to charge EVs at home. Then, it may cause to slow down the economy in the UK.

5 Discussion

The aim of the project is to minimise GHG emissions in the UK in 2050 by managing electricity generations and controlling EV demand. From Figure 38 to H1, it presents the results of integrating electricity generations and the controlled EV models.

As it demonstrated in Figure 38, the controlled EV model with deviation 0.4 may cause the gas generation in the UK to overload because normally it produces electricity between around 4,500 and 6,000 MW during the night time. But the EV demand at deviation 0.4 in 2050 boosts electricity demand up to more than twice in 2018 from 1:00 am to 3:00 am. On the other side, there is the small gap between EV demand in 2018 and 2050 at deviation 0.7. The estimation on the increasing demand in the future is only around 20 to 30 percent so that the deviation 0.7 increases fewer loads to the gas generations and less air pollution for the UK because gas generation produces less electricity at the night time. As a result, most electricity comes from wind turbines and nuclear power plants. Fortunately, Wind and nuclear energy are considered to be zero carbon dioxide emission

Next, the result shows the estimation on the carbon intensity of UK electricity demand combined with and without EV models in Figure 39. First, it is clear that adding EV recharging demand at night increases the carbon intensity because the electrical system depends more on the gas generation. However, the carbon content of gas generation which is 394 gCO_2/kWh is still lower than other fossil fuels such as coal at 937 gCO_2/kWh and oil 935 gCO_2/kWh. The EV demand with a low deviation which tends to have fewer distributions can cause an overshoot on electricity demand and carbon intensity as illustrated in Figure 39. Thus, the carbon intensity of the EV demand at deviation 0.7 becomes steadier than other graphs. Plus, the benefit of a higher distribution on EV demand helps to alleviate loads from consuming electricity in short of a period.

Interestingly, the period of high EV recharging demand in the deviation 0.7 follows the downward and upward trends of carbon intensity of UK electricity demand with uncontrolled EVs in Figure 40. The high EV demand is limited to recharges vehicles around between 10:30 pm and 5:30 am. This means when the total electricity demand is lower, the EV demand goes up and raises the carbon intensity by types of generations.

Similarly, the carbon intensity of UK electricity during the off-peak in winter is shifted up by the high demand of the controlled EV demand at deviation 0.7. But the carbon intensity of the controlled EV demand at the other time remains lower than uncontrolled EVs. Overall, in winter the UK consumes more energy and releases more CO_2 as shown in Figure 41 and Figure 40. Moreover, the project estimates that the UK in winter does not only have to generate more energy for heat and electricity but it is also likely to produce more electric power for EV demand than summer because the low temperature can cause the low performance in the carbon electrodes of Li-Ion batteries (Huang et al., 2000).

Table 6 compares the carbon intensity of the UK electricity demand with controlled and uncontrolled EV demand in summer and winter. Clearly, the controlled EV demand reduces almost 20 percent of the carbon estimation in the uncontrolled EV demand in summer, whereas controlling EV charging demand drops CO_2 emission around 10 percent in winter. Even though there are strong winds in winter, the proportion of renewable energy such as solar power became smaller which lead to the higher gas generation and raised the GHG emission as shown in Figure 19 and 41, respectively.

However, by analysing the potential impact of the controlled EV demand the project found that this methodology may not be able to apply with all types of users such as drivers at work and commercial users because these people may need to use vehicles to work during the charging periods. Also, the project needs to investigate more on the potential of wind energy during the off-peak loads after adding EV demand in 2050.

6 Conclusion

The demand on EVs tends to increase in the future. This demand may overload the UK electricity system at on-peak periods. Moreover, the UK generations that do not manage how to supply electricity will be caused to rise the GHG emissions in the future EV recharging demand (Figure 31). Therefore, the project has collected the data from many sources to apply for the estimation on UK electricity demand and the controlled EV demand profiles in 2050.

Generally, the demand on charging electric cars distributes throughout a day like the uncontrolled EV demand in Figure 21. In 2050, the project predicts that after controlling the demand by forcing drivers to charge EVs at the low carbon intensity or the off-peak load in Figure 32, there are high EV recharging demand in the short of periods. Hence, the project has managed the UK generations to supply the additional demand from EVs, while it simulated and integrated the controlled EV demand in 4 different deviations in order to find the suitable EV demand.
To conclude the simulation on the UK electricity demand and the controlled EVs and the results from the methodology, the project lists the main ideas below:

- Managing the generations to supply the additional demand like the future EV demand is necessary for reducing the CO_2 emissions
- By sharing the EV demand to other sources like renewable energy and nuclear power, the carbon intensity drops significantly
- In this case, the high deviations on EV recharging demand profiles helps to decrease the impact on overloading in a short of time greater than the low deviation. Also, the suitable EV recharging demand is at deviation 0.7. However, the result of the suitable EV demand profiles also depends on the daily electricity demand in the UK. For example, one day the off-peak period is shrunk shorter than usual so that means there will have a shorter period to charge EVs
- The UK electricity demand in winter is higher and more fluctuation than summer, and it causes to raise the carbon intensity and makes more difficult to reduce CO_2 emissions

- According to the impact on shifting EV recharging demand, the methodology of the project has more suitable for the EV users at home rather than workplace and commerce.

7 Future Work

Due to the several limitations within a short time, the project may not be able to cover all issues for the EV demand in the future. Thus, the project suggests further study to develop and improve the estimation on the UK electricity and the controlled EV demand profiles in 2050, including the accountability and feasibility of the UK electrical system.

- The project relies on the several sources and makes some assumptions that may have different conditions such as types of EVs, EV chargers, temperature, and it may also come from different areas. Hence, the project can improve the calculation of EV demand profiles to be more inaccurate by researching more comprehensive resources for the UK electricity system.

- The management on EV charging time and demand is one of many strategies to help to reduce carbon dioxide emission. Also, the project needs to apply this methodology along with other technologies. Thus, the project should use the benefits of technologies such as better batteries, faster EV chargers or a smart meter which helps to charge EVs during the off-peak load automatically in order to improve the UK electricity generations and CO_2 emissions.

- The project should review the methodology for the feasibility of the project on different days such as working days and weekdays which the demand may behave differently.

- The project will investigate the impact of the temperature to EV recharging demand which energy in a battery tends to decrease quicker than normal at the low temperature. This effect may lead to a higher EV demand than expected.

- The project may consider sharing more of EV demand in 2050 from gas to other sources. The capacity of other generations in 2050 is anticipated to become larger and more efficient in order to support the future demand. Particularly, the electricity from on-shore and off-shore wind turbines is likely to increase as the UK 2050 Calculator (Department of Energy & Climate Change, 2011).

- The project should regard about types of owners who use vehicles at different places and different purposes such as industry, commerce, public, domestic, home.
- The project may do more research on the future demand and generate the more suitable EV demand rather than using a normal distribution with different deviations. The project may use a specific mathematics or programme to optimise the demand and supply.
- The project does not consider to set the priority of each generation to provide electricity to the EV demand. Thus, it is interesting to do a research for prioritising the power generations to generate electric power for the future EV demand.
- The project may investigate the cost of managing UK supplies and controlling EV demand.

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Appendix

The raw data of the current electricity demand in the UK on typical days is divided by types of generations

Time	Gas	Oil	Coal	Nuclear	Wind	Pumped	Hydro	OCGT	Other	French	Irish IC	Dutch IC	East West	Biomass	Solar	Total
15:30	18878	0	0	6332	1897	945	357	0	25	1000	0	999	80	1864	3340	35717
16:00	18992	0	0	6338	1870	1219	451	0	25	1000	0	1001	59	2017	3210	36182
16:30	19033	0	0	6349	1886	1625	503	0	25	1000	0	1000	45	2006	2580	36052
17:00	18878	0	0	6495	2232	1247	549	0	25	1000	0	1000	45	1899	2060	35430
17:30	18425	0	0	6642	2810	1078	548	0	25	1000	48	1000	113	1846	1820	35355
18:00	18038	0	0	6665	3450	789	456	0	26	999	113	999	153	1866	1390	34944
18:30	17599	0	0	6678	3966	288	159	0	26	1000	113	1000	304	2042	994	34169
19:00	16550	0	0	6681	4457	449	134	0	26	1000	113	1001	453	2044	555	33463
19:30	15704	0	0	6683	4911	288	97	0	25	999	106	1000	499	1917	306	32535
20:00	14532	0	10	6685	5436	288	98	0	26	999	101	1000	495	1961	83	31714
20:30	13561	0	194	6680	5544	326	58	0	26	999	115	1000	500	1875	5.78	30884
21:00	12649	0	379	6692	5544	288	42	0	26	999	115	1000	504	1860	0.0536	30098
21:30	11400	0	500	6691	5687	288	41	0	26	999	115	999	504	1684	0.0457	28934
22:00	9474	0	759	6690	5748	0	41	0	26	1000	115	1000	504	1433	0.00877	26790
22:30	8045	0	918	6701	6013	0	41	0	25	900	115	900	504	1139	0.00452	25301
23:00	6567	0	759	6701	6223	0	41	0	25	902	115	900	504	1058	0.00578	23795
23:30	5831	0	952	6693	6278	0	42	0	26	751	115	709	504	1250	0.00703	23151
0:00	5505	0	907	6544	5974	0	46	0	26	753	115	709	504	1400	0.0134	22483
0:30	5724	0	937	6501	5951	0	46	0	26	752	115	710	504	1350	0.00361	22616
1:00	5293	0	937	6496	6166	0	46	0	25	753	115	709	504	1212	0.0038	22256
1:30	4916	0	935	6507	6243	0	45	0	25	752	115	710	504	1048	0.00988	21800
2:00	4694	0	938	6511	6213	0	41	0	26	753	115	709	504	1051	0.00436	21555
2:30	4804	0	948	6530	6046	0	41	0	26	752	115	765	500	1052	0.00631	21579
3:00	4607	0	945	6678	6012	0	41	0	26	753	115	757	500	993	0.00636	21427
3:30	4597	0	929	6739	6103	0	38	0	26	752	115	507	494	1002	0.00628	21302
4:00	4691	0	934	6744	5925	0	40	0	25	754	115	500	484	941	1.78	21155
4:30	4913	0	951	6740	6206	0	55	0	25	803	115	267	504	1004	41.4	21624
5:00	5372	0	950	6745	6834	0	56	0	25	802	116	338	504	1182	155	23079
5:30	6103	0	955	6748	6736	0	56	0	26	908	116	902	504	1211	327	24592
6:00	8484	0	946	6758	6812	292	55	0	26	879	80	814	429	1194	617	27386
6:30	11957	0	959	6756	6960	298	83	0	26	425	0	213	279	1337	1090	30383
7:00	12962	0	836	6756	7031	390	143	0	26	681	0	212	126	1303	1410	31876
7:30	13514	0	745	6755	6813	301	174	0	25	999	0	192	0	1341	1840	32699
8:00	13238	0	693	6745	6773	362	231	0	25	999	0	195	0	1369	2360	32990
8:30	13921	0	479	6779	6616	300	280	0	25	999	0	409	0	1418	3130	34356
9:00	13947	0	241	6856	6663	365	267	0	26	999	0	411	0	1426	3240	34441
9:30	13737	0	1	6881	6700	370	376	0	25	999	0	514	0	1426	3910	34939
10:00	13802	0	0	6937	6843	297	245	0	26	1000	0	517	0	1390	4420	35477
10:30	13514	0	0	6946	6720	344	248	0	25	999	0	690	0	1331	4560	35377
11:00	13863	0	0	6943	6600	305	180	0	25	999	0	692	0	1416	4360	35383
11:30	13913	0	0	6953	6597	291	122	0	25	999	0	783	0	1422	4380	35485
12:00	13795	0	0	7023	6387	556	77	0	25	999	0	786	0	1412	4260	35320
12:30	13660	0	0	7021	6579	295	49	0	25	999	0	984	0	1392	4460	35464
13:00	13526	0	0	7025	6444	364	49	0	26	999	0	984	0	1385	4510	35312
13:30	13578	0	0	7015	6386	342	50	0	26	999	0	1000	0	1385	4660	35441
14:00	13360	0	0	7026	6704	291	58	0	26	999	0	967	0	1379	4640	35450
14:30	14148	0	0	7045	6208	433	68	0	25	998	0	548	0	1396	4770	35639
15:00	14901	0	0	7047	5793	448	166	0	26	999	0	550	0	1402	4750	36082

Table 8 The UK electricity demand from 19th to 20th of June, 2018 (Elexon, 2018)

After managing the UK generations by sharing the EV demand from gas to all renewables, nuclear power, and biomass (case 3), the project adds the uncontrolled EV demand with the UK electricity demand management.

Time	Gas	Nuclear	Wind	Pumped	Hydro	OCGT	Other	French	Irish IC	Dutch IC	East West	Biomass	Solar	Total
15:30	16479	6332	1897	945	357	0	21	857	0	856	69	1864	3340	33016
16:00	16427	6338	1870	1219	451	0	21	857	0	857	51	2017	3210	33318
16:30	16460	6349	1886	1625	503	0	21	857	0	857	39	2006	2580	33182
17:00	16370	6495	2232	1247	549	0	21	857	0	857	39	1899	2060	32625
17:30	15954	6642	2810	1078	548	0	21	857	41	857	97	1846	1820	32571
18:00	15922	6665	3450	789	456	0	22	856	97	856	131	1866	1390	32500
18:30	15858	6678	3966	288	159	0	22	857	97	857	260	2042	994	32078
19:00	15126	6681	4457	449	134	0	22	857	97	857	388	2044	555	31667
19:30	14491	6683	4911	288	97	0	21	856	91	857	427	1917	306	30945
20:00	13509	6685	5436	288	98	0	22	856	87	857	424	1961	83	30314
20:30	12623	6680	5544	326	58	0	22	856	99	857	428	1875	6	29540
21:00	11793	6692	5544	288	42	0	22	856	99	857	432	1860	0	28809
21:30	10680	6691	5687	288	41	0	22	856	99	856	432	1684	0	27763
22:00	8929	6690	5748	0	41	0	22	857	99	857	432	1433	0	25757
22:30	7562	6701	6013	0	41	0	21	771	99	771	432	1139	0	24336
23:00	6036	6701	6223	0	41	0	21	773	99	771	432	1058	0	22804
23:30	5080	6693	6278	0	42	0	22	643	99	607	432	1250	0	21962
0:00	4602	6544	5974	0	46	0	22	645	99	607	432	1400	0	21148
0:30	4612	6501	5951	0	46	0	22	644	99	608	432	1350	0	21068
1:00	4039	6496	6166	0	46	0	21	645	99	607	432	1212	0	20566
1:30	3538	6507	6243	0	45	0	21	644	99	608	432	1048	0	19986
2:00	3202	6511	6213	0	41	0	22	645	99	607	432	1051	0	19626
2:30	3027	6530	6046	0	41	0	22	644	99	655	428	1052	0	19356
3:00	2753	6678	6012	0	41	0	22	645	99	648	428	993	0	19129
3:30	2625	6739	6103	0	38	0	22	644	99	434	423	1002	0	18925
4:00	2593	6744	5925	0	40	0	21	646	99	428	415	941	2	18654
4:30	2630	6740	6206	0	55	0	21	688	99	229	432	1004	41	18959
5:00	2866	6745	6834	0	56	0	21	687	99	290	432	1182	155	20181
5:30	3501	6748	6736	0	56	0	22	778	99	773	432	1211	327	21501
6:00	5545	6758	6812	292	55	0	22	753	69	697	367	1194	617	23992
6:30	8527	6756	6960	298	83	0	22	364	0	182	239	1337	1090	26680
7:00	9532	6756	7031	390	143	0	22	583	0	182	108	1303	1410	28177
7:30	10268	6755	6813	301	174	0	21	856	0	164	0	1341	1840	29172
8:00	10186	6745	6773	362	231	0	21	856	0	167	0	1369	2360	29664
8:30	10963	6779	6616	300	280	0	21	856	0	350	0	1418	3130	31124
9:00	11283	6856	6663	365	267	0	22	856	0	352	0	1426	3240	31536
9:30	11175	6881	6700	370	376	0	21	856	0	440	0	1426	3910	32156
10:00	11502	6937	6843	297	245	0	22	857	0	443	0	1390	4420	32956
10:30	11399	6946	6720	344	248	0	21	856	0	591	0	1331	4560	33016
11:00	11844	6943	6600	305	180	0	21	856	0	593	0	1416	4360	33118
11:30	11941	6953	6597	291	122	0	21	856	0	671	0	1422	4380	33254
12:00	11798	7023	6387	556	77	0	21	856	0	673	0	1412	4260	33064
12:30	11623	7021	6579	295	49	0	21	856	0	843	0	1392	4460	33139
13:00	11414	7025	6444	364	49	0	22	856	0	843	0	1385	4510	32912
13:30	11498	7015	6386	342	50	0	22	856	0	857	0	1385	4660	33071
14:00	11129	7026	6704	291	58	0	22	856	0	828	0	1379	4640	32933
14:30	11732	7045	6208	433	68	0	21	855	0	469	0	1396	4770	32998
15:00	12277	7047	5793	448	166	0	22	856	0	471	0	1402	4750	33232

Table 9 The estimation of the UK electricity plus the uncontrolled EV demand in 2050

The UK electricity demand management added the controlled EV demand in 2050

Time	Gas	Nuclear	Wind	Pumped	Hydro	OCGT	Other	French	Irish IC	Dutch IC	East West	Biomass	Solar	Total
15:30	13756	6332	1897	945	357	0	21	857	0	856	69	1864	3340	30293
16:00	13804	6338	1870	1219	451	0	21	857	0	857	51	2017	3210	30695
16:30	13863	6349	1886	1625	503	0	21	857	0	857	39	2006	2580	30585
17:00	13798	6495	2232	1247	549	0	21	857	0	857	39	1899	2060	30053
17:30	13356	6642	2810	1078	548	0	21	857	41	857	97	1846	1820	29973
18:00	13030	6665	3450	789	456	0	22	856	97	856	131	1866	1390	29608
18:30	12708	6678	3966	288	159	0	22	857	97	857	260	2042	994	28927
19:00	11773	6681	4457	449	134	0	22	857	97	857	388	2044	555	28314
19:30	11088	6683	4911	288	97	0	21	856	91	857	427	1917	306	27542
20:00	10092	6685	5436	288	98	0	22	856	87	857	424	1961	83	26896
20:30	9352	6680	5544	326	58	0	22	856	99	857	428	1875	6	26269
21:00	8757	6692	5544	288	42	0	22	856	99	857	432	1860	0	25773
21:30	8019	6691	5687	288	41	0	22	856	99	856	432	1684	0	25103
22:00	6940	6690	5748	0	41	0	22	857	99	857	432	1433	0	23767
22:30	6506	6701	6013	0	41	0	21	771	99	771	432	1139	0	23280
23:00	6291	6701	6223	0	41	0	21	773	99	771	432	1058	0	23059
23:30	6934	6693	6278	0	42	0	22	643	99	607	432	1250	0	23815
0:00	8140	6544	5974	0	46	0	22	645	99	607	432	1400	0	24686
0:30	9772	6501	5951	0	46	0	22	644	99	608	432	1350	0	26228
1:00	10626	6496	6166	0	46	0	21	645	99	607	432	1212	0	27153
1:30	11152	6507	6243	0	45	0	21	644	99	608	432	1048	0	27600
2:00	11263	6511	6213	0	41	0	22	645	99	607	432	1051	0	27687
2:30	11072	6530	6046	0	41	0	22	644	99	655	428	1052	0	27402
3:00	10059	6678	6012	0	41	0	22	645	99	648	428	993	0	26435
3:30	8834	6739	6103	0	38	0	22	644	99	434	423	1002	0	25134
4:00	7516	6744	5925	0	40	0	21	646	99	428	415	941	2	23577
4:30	6235	6740	6206	0	55	0	21	688	99	229	432	1004	41	22564
5:00	5198	6745	6834	0	56	0	21	687	99	290	432	1182	155	22513
5:30	4666	6748	6736	0	56	0	22	778	99	773	432	1211	327	22665
6:00	5864	6758	6812	292	55	0	22	753	69	697	367	1194	617	24311
6:30	8369	6756	6960	298	83	0	22	364	0	182	239	1337	1090	26522
7:00	8815	6756	7031	390	143	0	22	583	0	182	108	1303	1410	27460
7:30	9045	6755	6813	301	174	0	21	856	0	164	0	1341	1840	27949
8:00	8615	6745	6773	362	231	0	21	856	0	167	0	1369	2360	28092
8:30	9043	6779	6616	300	280	0	21	856	0	350	0	1418	3130	29204
9:00	9029	6856	6663	365	267	0	22	856	0	352	0	1426	3240	29283
9:30	8735	6881	6700	370	376	0	21	856	0	440	0	1426	3910	29717
10:00	8718	6937	6843	297	245	0	22	857	0	443	0	1390	4420	30172
10:30	8442	6946	6720	344	248	0	21	856	0	591	0	1331	4560	30059
11:00	8789	6943	6600	305	180	0	21	856	0	593	0	1416	4360	30063
11:30	8825	6953	6597	291	122	0	21	856	0	671	0	1422	4380	30137
12:00	8730	7023	6387	556	77	0	21	856	0	673	0	1412	4260	29996
12:30	8574	7021	6579	295	49	0	21	856	0	843	0	1392	4460	30091
13:00	8462	7025	6444	364	49	0	22	856	0	843	0	1385	4510	29960
13:30	8496	7015	6386	342	50	0	22	856	0	857	0	1385	4660	30068
14:00	8276	7026	6704	291	58	0	22	856	0	828	0	1379	4640	30081
14:30	9037	7045	6208	433	68	0	21	855	0	469	0	1396	4770	30303
15:00	9727	7047	5793	448	166	0	22	856	0	471	0	1402	4750	30682

Table 10 The estimation of the UK electricity plus the controlled EV demand in 2050 (deviation 0.4)